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Cross-country Comparison of the Case Studies under WP7

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Table of Contents

1. Introduction to the WP7 Project component

This report is aimed at comparing the results of the fuel cycle externality studies performed for 5 non-EU countries under the Work Package 7 (WP7) of the CASES project. It is part of the EU-funded CASES project.

1.1 General Information about WP7

The WP7 generally has two objectives, namely: (1) To develop a methodological framework that can be used to calculate the external costs of energy fuel cycles in Brazil, Bulgaria, China, India and Turkey; and (2) To undertake studies of at least two national fuel cycles in each of these countries. The results should generate new insights into the external costs of fuel cycles in EU compared with cost levels in non-EU countries. The participating institutions are listed in Table 1 below.

Table 1. List of participants

Participant name	Short Name	Country
National Laboratory for Sustainable Energy	RISOE DTU	Denmark
Fundação COPPETEC	COPPETEC	Brazil
Indian Institute of Management Ahmedabad	IIMA	India
Energy Research Institute	ERI	China
Energy Agency of Plovdiv	EAP	Bulgaria
Turkiye Bilimsel ve Teknik Arastirma Kurumu – Marmara Research Center. Institute of Energy	TUBITAK	Turkey

The WP 7 develops estimates of external costs for a 25 year time frame based on a detailed assessment of the selected fuel cycles. Some country studies, however, have decided to focus on current external costs without considering future developments. The participating countries estimate the costs on the basis of available energy use scenarios (as covered in WP1) and more detailed fuel cycle studies. Special attention is given to inclusion of health damage estimates. Data are generated based on available national energy models, which for India includes MARKAL and AIM, and IPAC for China.

The WP 7 applies a simplified methodological framework that can be used to transform scenario- and model based cost data into the database system that have been developed in the ExterneE project and subsequent project activities. This framework allows cost data generated by the participating non-EU countries to be compared with the cost of fuels cycles in the EU (RISOE DTU, COPPETEC, IIMA, ERI, TUBITAK, and EAP).

Deliverables

Under WP7, 7 research reports have been submitted, including: (1) a methodology report; (2) 5 national reports on external costs of fuels cycles in the participating non-EU countries; and (3) a *report* on the comparative assessment of fuel cycle costs and methodological challenges across the participating countries.

Due to limited financial resources, the national case studies under WP7 are mainly based on results of existing research in the 5 participation countries. In the EU, there has been long-term government support to such kinds of studies and the ExternE project lasted 15 years and involved more than 20 European research institutes. Hence, the research is much better established and the methodologies are better coordinated. In the countries covered by WP7, the studies are much less systematic and the existing case studies are often based on different models and approaches. It has therefore been decided to simplify the ExternE methodologies for easier application by the country teams and the methodology report has been prepared for linking the ExternE framework and the different energy and environment impact models applied in the 5 countries.

1.2 Part of general CASES project

The WP7 is one of 12 work packages covered under the CASES project. Activities under WP7 are an integrated part of the CASES project and closely related to the other ongoing activities.

1.2.1 About the CASES Project

CASES is the abbreviation of 'Costs Assessment of Sustainable Energy Systems', a Co-ordinated Action funded by the European Commission under the Sixth Framework Program, Priority 6.1.3.2.5, Sustainable Energy Systems. The project intends to develop a consistent and comprehensive picture of the full cost of energy and to make this knowledge available to all stakeholders.

The three key objectives of this Co-ordinated Action are:

- To compile coherent and detailed estimates of private and external costs of energy production for different energy sources at the national level for the EU-25 Countries and for some non-EU Countries under energy scenarios to 2030.
- To evaluate policy options for improving the efficiency of energy use taking into account the full cost data.
- To disseminate research findings to energy sector producers and users and to the policy making community.

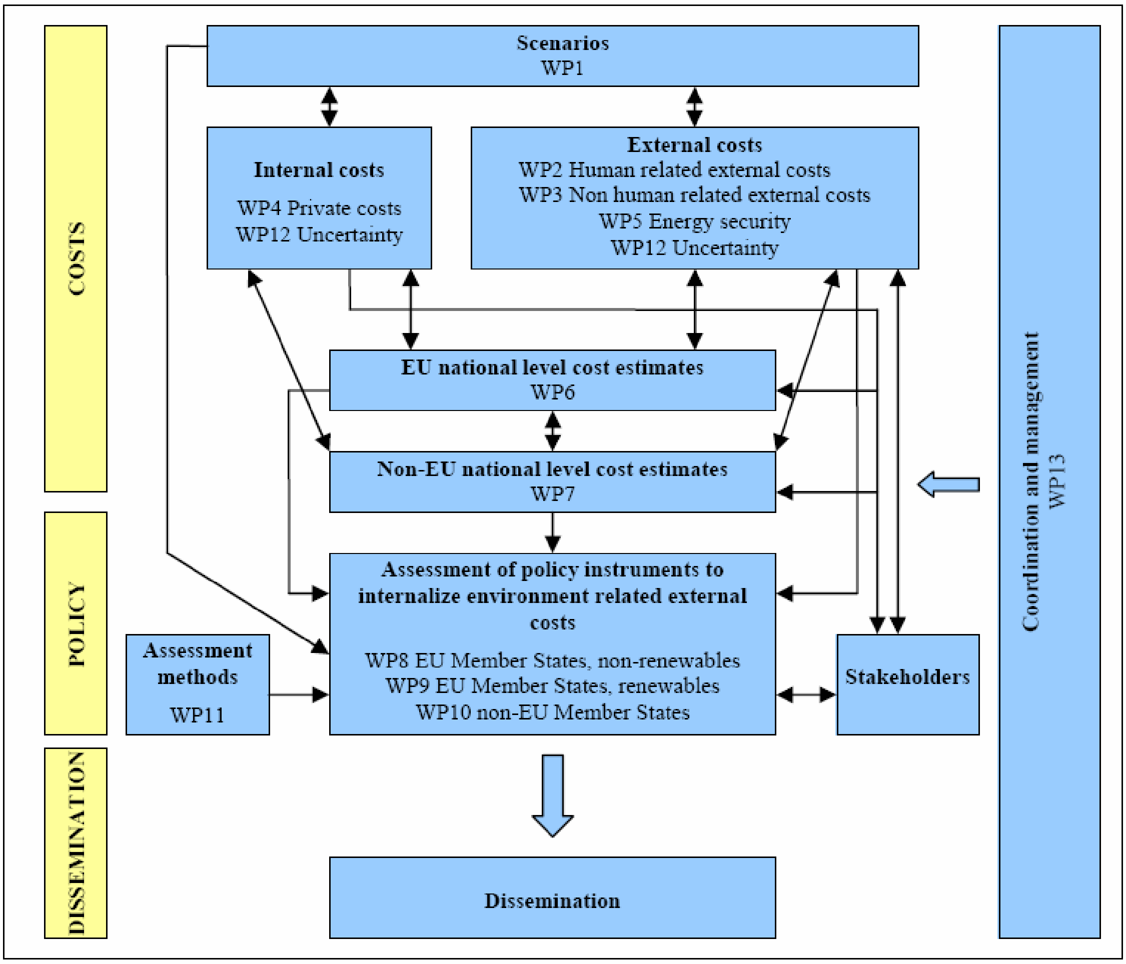
1.2.2 Activities under the CASES Project

1) Research. The first objective of the CASES Project is to compile a consistent and detailed set of estimates of the private and external costs of energy production for different energy sources at the national level for the EU-25 Countries and Brazil, Bulgaria, China, India and Turkey, under energy scenarios to 2030.

2) Policy assessment. The second objective involves applying the comparative cost data of different energy technologies, to the assessment of alternative policy options for improving the efficiency of energy use and reducing its impact on environment over the next decades.

3) Dissemination of the knowledge on energy costs. Once evaluated and brought into a coherent framework, the results of the different components of the project are of great interest for the energy sector producers and users, as well as for the policy-making community.

Figure 1. Diagram of CASES Work Packages



Source: http://www.feem-project.net/cases/documents/flyers/CASES%20brief%20description.pdf

The assessment of the full cost estimates of energy production allows policy-makers to become more aware of the consequences that different fuels and technologies have on human health, the environment and the society as a whole. The project disseminates research findings to energy sector producers and users, and to the policy-making community.

The CASES project started on the 1st of April 2006 and will last for 30 months. Altogether 26 leading research institutions located in Europe and a few developing countries participate in the implementation of this project.

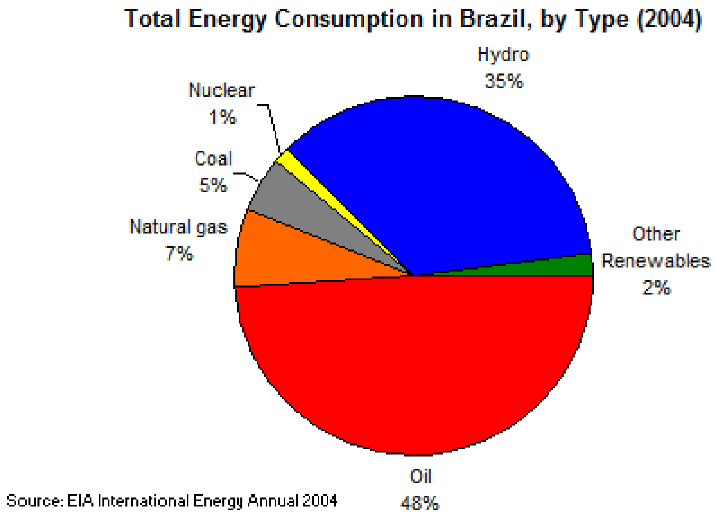
1.3 The 5 Countries Covered in the Case Studies

The five countries included in the WP7 have very different size and energy sector characterises. The sections below briefly touch upon the energy sectors of the countries included in the study.

1.3.1 Brazil

Brazil is a large developing country. The country has a significant use of renewables since a large share of its power generation is from hydro. Besides, Brazil is also a major producer and user of ethanol and bio-diesel and more than half of the cars used in Brazil run on pure biofuel or a mixture of biofuel and convnetional oil. Brazil is the world's 8th largest economy in terms of purchasing power and the 10th largest economy at market exchange rates (World Bank. 2007). The largest share of Brazil's total energy consumption comes from oil (48 percent including ethanol), followed by hydroelectricity (35 percent) and natural gas (7 percent). The large share of hydroelectricity in Brazil's energy mix displays the dependence of electricity generation from hydroelectric dams and currently hydropower accounts for 87 percent of the country's electricity production. Natural gas currently holds a small share of total energy consumption, but attempts to diversify electricity generation from hydropower to gas-fired power plants could cause natural gas consumption to grow in coming years (EIA. 2007).

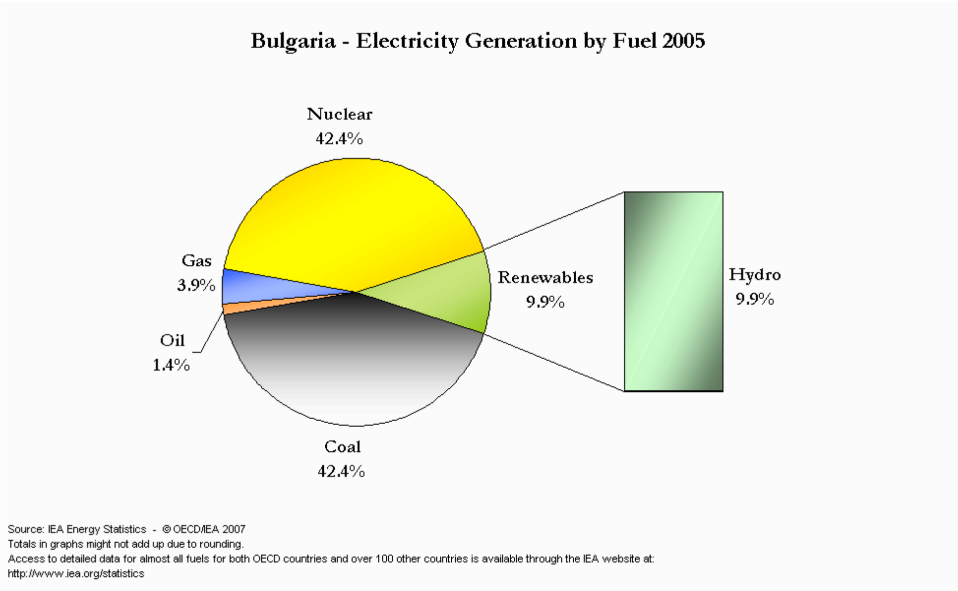
Figure 2. Total Energy Consumption in Brazil, by Type (2004)



1.3.2 Bulgaria

The Bulgarian power sector is, as shown in Figure 3, very dependant on coal and nuclear. However, hydropower is also a significant power source. Most of the hard coal is imported while the lignite is from domestic reserves. Bulgaria imports almost all its natural gas from Russia.

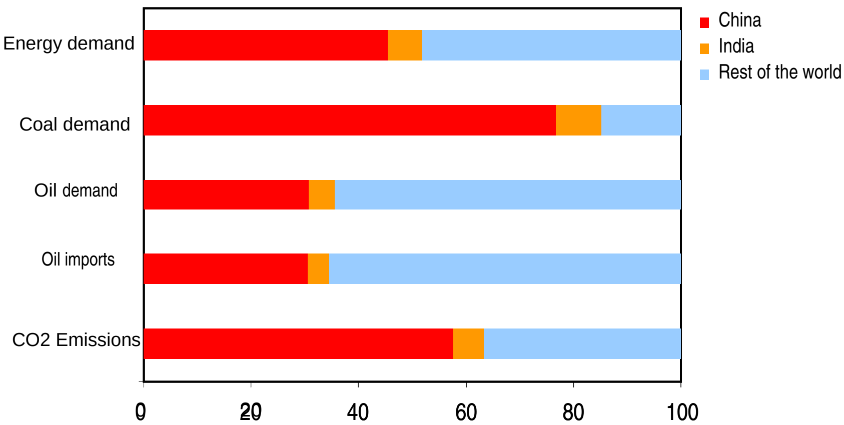
Figure 3. Bulgaria electricity generation by fuel, 2005



1.3.3 China and India

The energy policies and activities of large developing countries, especially China and India, will have very significant impact on the world. As indicated in Figure 4, during the period between 2000 and 2006, China and India were responsible for about half of the worlds increase in energy consumption and more than half of the increase in CO_2 emissions from energy related activities. Besides, over 80% of the increase in world coal demand since 2000 comes from these two big emerging countries.

Figure 4. Increase in World Primary Energy Demand, Imports & Energy-Related CO_2 Emissions in the Reference Scenario, 2000-2006

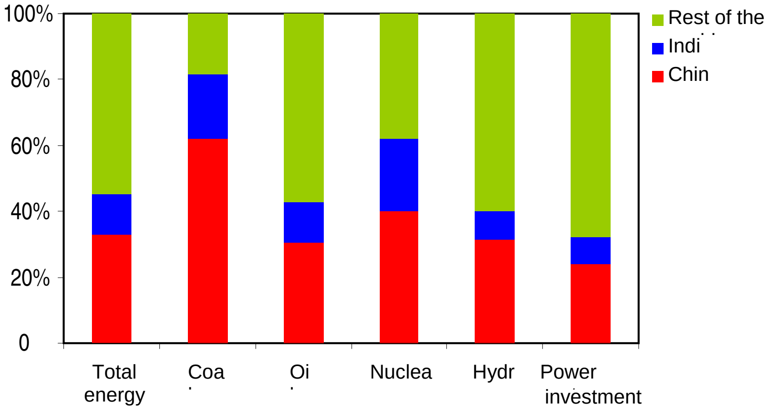


Source: WEO 2007, IEA

In view of the rapid economic growth and income and living standard improvements in these two countries, it is expected that the rapid increase in energy consumption will continue. The rising importance of China and India in shaping the future of world energy demand and consumption has attracted wide attention. The International Energy Agency devoted its World Energy Outlook 2007 (WEO 2007) to China and

India. According to IEA estimates, if the current trends and the existing policies continue, China and India will contribute more than 40% to the increase in global energy demand to 2030. Figure 5 shows the IEA modelling results of primary energy demand and investment till 2030.

Figure 5. Increase in Primary Energy Demand & Investment between 2005 & 2030 as Share of World Total



Source: 2007, IEA

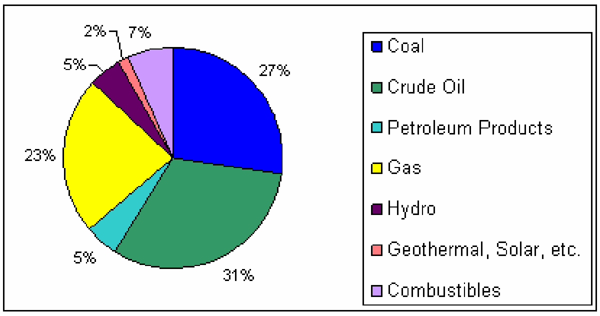
In both China and India, coal is the most important form of energy due to the availability of large domestic reserves and low private costs. However, the combustion of large amounts of coal also causes severe local air pollution, land damage and water pollution, as well as high GHG emissions. It is important to estimate these external costs and disseminate the modelling results among business decision makers and policy makers, so as to stimulate the shift in these countries toward more sustainable energy supply and consumption.

1.3.4 Turkey

Turkey is a country about the size of Metropolitan France and the UK combined. Located in the area between the EU in the west and Central Asia in the east, Turkey has come to acquire increasing strategic significance, especially due to the fact that it is a big neighbour of the EU and located on the way of EU's fossil fuel import from Middle East, Russia, and Central Asia. It is also the only IEA member country among the five countries covered under WP7.

As indicated in the Figure 6 below, Turkey's main energy supply is in the form of coal, oil, and natural gas, while around 14% of its primary energy supply comes from hydro, geothermal, solar, biomass and other renewable sources.

Figure 6. 2004 Energy Balances for Turkey



Source: Based on IEA data, http://www.iea.org/Textbase/stats/balancetable.asp?COUNTRY_CODE=TR

2. Overview of the Fuel Cycles Covered in the Country Studies

2.1 Fuel Cycles Covered

The five country teams have analyzed the fuel cycles considered most important for each particular country and hence several different fuel cycles have been analyzed in the country studies. Although most studies have analyzed the main externalities of the selected fuel cycles, some studies focus on specific externalities of national concern. The best covered fuel cycle is the coal fuel cycle which has been analyzed by four of the five participating country teams. These include Bulgaria, China, India and Turkey. The natural gas fuel cycle comes second and has been analyzed for three countries, namely Brazil, Bulgaria and China. Bio-fuels have been analyzed for Bulgaria and Turkey, while hydro power has been analyzed for Brazil and Bulgaria. In addition, Bulgaria has included some other renewable energy technologies such as wind and solar PV.

2.2 Stages and Burdens Analysed

The different fuel cycles consists of several major stages involving various burdens to the environment. Since each fuel cycle stage brings about a large number of burdens, it is necessary to identify a range of priority burdens for further analysis. This is possible since some burdens are several magnitudes larger than others and the minor ones are therefore insignificant. The priority burdens are accordingly believed to make up the main externalities (CASES M 7.4. 2007; EC. 1997). The identification of priority burdens for the various fuel cycle stages requires careful analysis and this has been done through externality research over the past decades.

The country studies have selected different fuel cycle stages and priority burdens for in-dept analysis. Table 2 shows an overview of the major fuel cycle stages and priority burdens of the various fuel cycles and the extent to which they have been analyzed by the different country studies. The level of analysis in the country studies has been categorized into two levels, namely Quantitative (labelled “Q”) and Non-Quantitative (labelled “NQ”). The burdens are considered to be analyzed quantitatively if specific damage costs have been estimated or if the data provided by the country teams is sufficiently detailed to enable the coordinating team to calculate specific damage costs. The burdens are considered to be analyzed non-quantitatively if no specific damage costs have been estimated and the data are insufficient for calculation of exact damage costs. Burdens that have not been considered by the country studies are marked with “-“.

Table 2 (next page). Overview of fuel cycles, stages and burdens analyze.

Fuel cycle	Fuel cycle stage	Burdens	Brazil	Bulgaria	China	India	Turkey
Coal/lignite power	Facilities construction/ decommissioning	Air pollution GHG emissions Occupational health		- - -	- - -	- - -	NQ NQ NQ
	Mining	Air pollution GHG emissions Land damage Occupational health Wastes		NQ NQ Q - NQ	NQ NQ NQ NQ NQ	Q Q NQ - -	NQ - - NQ -
	Coal/lignite transport	Air pollution GHG emissions		- - -	NQ NQ	Q Q	Q Q
	Coal/lignite beneficiation	Air pollution GHG emissions Wastes		- - -	- - -	Q Q -	- - -
	Power generation/ transmission	Air pollution GHG Emissions Occupational health Wastes		Q Q - NQ	Q Q - Q	Q Q - Q	Q Q NQ NQ
Natural gas power	Facilities construction/ (decommissioning)	Air pollution GHG emissions Occupational health	NQ NQ NQ	- - -	- - -		
	Gas exploitation	GHG emissions Land damage Occupational health Wastes	NQ - NQ -	- - - -	NQ NQ - NQ		
	Gas transport and treatment	Air pollution GHG emissions	NQ NQ	NQ NQ	NQ NQ		
	Power generation/ transmission	Air pollution GHG Emissions Occupational health	Q Q NQ	Q Q -	Q Q -		
Bio-diesel/ biomass	Biomass cultivation	Air Pollution GHG emissions Ecological effects Land use changes		- Q -			- NQ - -
	Biomass/oil transportation	Air Pollution GHG emissions Accidents					- NQ -
	Conversion processes and blending	Air Pollution GHG emissions Wastes					- NQ -
	Combustion/power generation	Air Pollution GHG emissions Occupational health					- NQ -
Hydro power	Facilities construction/ (decommissioning)	GHG emissions Occupational health Public health	- NQ Q	- Q -			
	Power generation/ transmission	GHG emissions Occupational health Public health	- NQ Q				
Wind power & Solar PV	Turbine construction/ (decommissioning)	Air pollution GHG emissions Occupational health		- Q -			
	Power generation/ transmission	Noise Visual effects Other impacts					

For the coal/lignite fuel cycle, major stages include facility construction/decommissioning, coal/lignite mining, coal/lignite transport, coal/lignite beneficiation and power generation/transmission. The priority burdens have been grouped into GHG emissions, air pollution, wastes, land damage and occupational health. As shown in Table 2, all country studies have quantified GHG emissions and air pollution from the power generation stage. However, there are large differences in the analysis of upstream processes by the country teams. The India country study includes all fuel cycle stages besides from construction/decommissioning of facilities, while the Chinese study covers the coal mining stage, the generation/transmission stage and waste water consumption during coal washing, as well as coal stockpiling. The Turkish study covers the coal transport and power generation stages. In the Bulgarian study, only the power generation stage has been considered. The total cost numbers for the country studies thereby include burdens from different full cycle stages and hence, they cannot be directly compared. However, since the power generation stage generally is viewed as the main externality source from fossil fuel based power generation, the final numbers are to some extent comparable.

The major stages in the natural gas fuel cycle are construction/decommissioning of facilities, gas exploitation, gas treatment and transport and power generation/transmission. The priority burdens can be grouped into GHG emissions, air pollution, wastes, land damage and occupational health. As shown in Table 2, only air pollution and GHG emissions from the power generation stage have been analyzed quantitatively for the three country studies. This means that in all studies burdens from upstream stages have been neglected and the total damage costs might therefore be slightly underestimated. However, it facilitates cross-country comparison since the studies all analyze the same priority burdens.

In the biomass fuel cycle, the major stages are slightly different from the fossil fuel based power generation systems as shown in Table 2. The stages include biomass cultivation, biomass/oil transportation, conversion processes and blending and finally combustion/power generation. These stages can be broken down into several sub-stages for separate analysis depending on biomass schemes, and this has also been done in the Turkish study. The priority burdens included in the fuel stages can be grouped into GHG emissions, air pollution, ecological effects, land use changes, accidents, occupational health and wastes. Even though both the Bulgarian and Turkish studies include biomass, the burdens have only been quantitatively analyzed in the Bulgarian study. However, the Bulgarian study has not divided the costs into different stages and burdens. Instead, it only provides a total value of the external costs of biomass fuel cycle.

The hydro fuel cycle and other alternative technologies as wind and solar can be separated into two major stages, namely facility construction/decommissioning and power generation/transmission. The main priority burdens for these technologies can be separated into GHG emissions, occupational health and public health, noise, visual effects and other impacts. The Brazilian study focuses on quantifying the public health effects of hydropower and has not considered GHG emissions, while the Bulgarian study only gives a total damage cost. This means that some externalities are not considered in the Brazilian study while it is a bit unclear what has been included in the estimates for Bulgaria. Since the Brazilian study focus on dam based hydropower, it can only be directly compared with the dam-based hydro analyzed for Bulgaria.

3. Methodological issues

This section focuses on the methodological approaches, available in the existing literature, to external cost assessment on different fuel cycles, including coal fired power generation, natural gas fired power generation, bio-fuel cycle, and hydro, wind and solar energy cycles.

3.1 General background of the ExternE approach

"ExternE" (External costs of Energy) is a framework for assessing external costs of energy developed under the support of the European Commission during 15 years starting in 1991. In the ExternE project series, the impact pathway methodology has been developed, improved and applied for calculating externalities from electricity and heat production as well as transport. It has proved to be a workable methodology for detailed quantification of the external costs of various fuel cycles.

The ExternE project has involved more than 50 research teams in over 20 countries. The effects of electricity generation are physically, environmentally, and socially complex and difficult to estimate, and involve very large, sometimes ultimately irresolvable, uncertainties, unpredictability, and differences of opinion. Despite these difficulties, ExternE has become a well-recognised source for methods and results of externalities estimation.

The term 'fuel cycle' refers to the chain of processes linked to the production of electricity or other services from a given fuel. For example, the assessment of the coal fuel cycle includes evaluation of the impacts associated with: (1) construction of a new power plant; (2) coal mining; (3) limestone quarrying (for flue gas desulphurisation, where used); (4) transport of coal, wastes, other materials; (5) power generation; (6) electricity transmission and (7) waste disposal.

As defined by the ExternE project, a typical life-cycle external cost analysis generally consist of the following steps (see Figure 8):

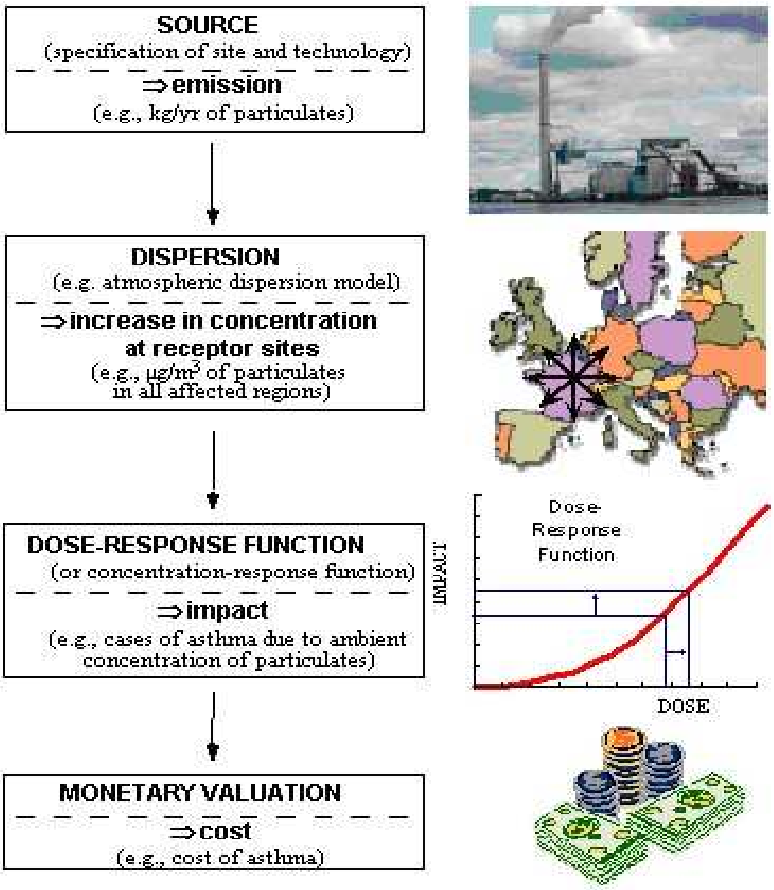
1) Define the steps and emission/burdens of each process to be covered. The burdens from the different steps and the damages caused to society may vary in a wide range.

2) Dispersion: estimate the scope and extent of impacts, taking into account the local climate and geographic situations.

3) The dose-response function: given the local demographic, social, and ecological conditions, determine the size of impacts caused by the emissions/burdens.

4) Monetisation: estimate the monetary value of the different impacts and aggregate all costs of different impacts to get the total external cost of a fuel cycle External cost analysis usually begins with the identification of the stages of the fuel cycle under assessment.

Figure 8. The ExternE Methodology Framework



Source: ExternE, http://www.externe.info/

The ExternE project lists three important principles for externality estimates:

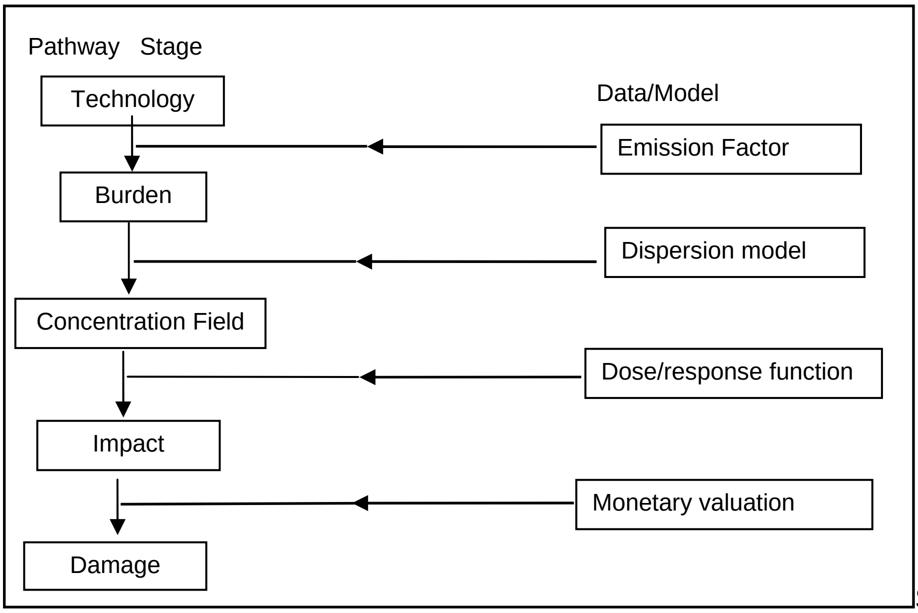
- *Transparency* to show how the work was done, and what was assessed and what was not.
- *Consistency* to allow valid comparisons to be made between different fuel cycles and different types of impact within a fuel cycle.
- *Comprehensiveness* all impacts of a fuel cycle should be considered, even though many may not be investigated in detail.

3.1.1 Damage Function Approach

The impact assessment and valuation are in the ExternE context performed using the 'damage function' or 'impact pathway' approach. This approach assesses impacts in a logical manner, using the most appropriate models and data available. Methods range from the use of simple statistical relationships, as in the case of occupational health effects, to the use of series of complex models and databases, as in the cases of acid rain and global warming effects.
This approach requires a detailed definition of both the fuel cycle and the system within which the fuel cycle operates, with respect to both time and space. Typical data required are:

- Technological and emissions data.
- Specifications of the fuel used.
- Meteorological conditions affecting dispersion of atmospheric pollutants.
- Demographic data.
- Condition of ecological resources.
- The value of systems of individuals, which determine the valuation of non-marketed goods.

Figure 7. Typical impact pathway approach under the ExternE:



Source:

Source : http://externe.jrc.es/overview.html

3.2 Methodology for External Cost Assessment of Coal-fired Power Generation Fuel Cycles

As required in the project design, under the WP7 component, in May 2007, Risoe National Laboratory prepared a report (M7.4) on the methodological framework for life-cycle analysis on different fuel cycles. It is aimed at offering simple guidance for the case studies conducted in each of the 5 countries.

In the M7.4 Report, the country teams are given the following advices on coal-fired power generation fuel cycles.

The impacts to be considered as most relevant are those caused by atmospheric emissions from the power generation stage on human health, materials, crops and ecosystems and global warming. In addition, impacts on occupational health should be analyzed, which are most important for underground coal mining. Discharges of effluents from mining activities might have significant impacts on groundwater systems, but these effects are very difficult to quantify.

Table 3. Methodology for Assessing the External Cost of Coal-fired Fuel Cycle

Fuel cycle stage	**Burdens**	**Guidance on Data and Calculation**
Mining	CH_4 emission Waste water Solid waste Land damage Health hazards and mortality	• Base year: 2005 • Estimate amount of coal use for power generation in base year • Find data about amount of domestically mined coal used • Coal mined * CH_4 emission factor = CH_4 emissions (if domestic CH_4 emission factor unavailable, use IPCC 2006 default data) • Use country-specific data about waste water, solid waste and land degradation generated, to produce each ton of coal. If data are not available, use EU per ton average data • Occupational health hazards and mortality during coal mining
Coal/lignite transport	Fuel consumption during transport and the related CO_2, SO_2, NO_x, and PM emissions	• Calculate the fuel consumption for coal transport: estimate total coal transport, split it into various transport modes as railway, waterway and road, based on national statistics. • Emission factors for CO_2, SO_2, NO_x, and particulates, preferably use national specific data. If unavailable, use IPCC default data or expert judgment. • Other externalities, such as solid waste generation at terminals and spillage during transport considered minor and ignored.
Coal/lignite beneficiation	Air pollution GHG emissions Wastes	• Estimate waste water and soil pollution from country. specific values for the amount of coal benefited. • Estimate the waste water discharged into public systems without treatment. • Estimate total power consumption for the coal beneficiation process. Use national average emission factor of electricity or other fossil fuel used to estimate total air pollutants emitted due to power or fossil fuel consumption.
Power generation/ transmission	Air pollution GHG Emissions Fly ash	• Estimate pollutant loads from power generation based on total coal consumed or directly as model output. • Fly ash released from stack should be included.
Ash disposal	Fuel consumption and the associated emissions	• Estimate total fly ash generated • Ash disposal options: slurry in large ash-ponds, use in cement production, road construction, brick making, and agriculture. Particulates dispersed during the disposal and generally ≤1%. • Fossil fuel used for ash disposal
Calculate the external costs		• Monetary value of each externality. Based on country-specific studies or data from the ExternE project or any other secondary sources. • Unit costs are deflated based on per capita GDP comparison of countries (PPP) to get a likely per unit costs of various externalities for the target country.

It can be seen that although the construction and de-commissioning of a coal-power plant consumes materials, involve transportation of concrete, steel, sand and other heavy building materials, which lead to energy consumption and various emissions, this step is not included in the methodology guidance above for the external cost assessment under WP7. As collecting, estimating, and modelling external costs often take time and involves labour-intensive process, in some cases, the researchers choose to neglect the unimportant environmental burdens and processes, in some cases, they are included to increase the accuracy and coverage of the calculation.

3.2.1 Valuation of the impacts

Valuation of the effects on recreation, cultural objects, and ecosystems. The ExternE calculate the external costs of each damage based on expert estimates of impacts and unit values (i.e. recreation value per activity day) from benefit transfer. Damage estimates for the overall effects on recreation, cultural heritage, and ecosystems from the new Contingent Valuation study. The Contingent Valuation study includes face-to-face interviews, questionnaire surveys to find out the willingness to pay by local residents.

Valuation of the occupational health impacts. The ExternE study uses relevant national statistics to estimate the accident rates of minor injuries, major injuries, and deaths related to the construction and operation of a power plant and transmission lines. The value of a statistical life (2.6 million ECU (European Currency Unit), used to value public mortality, is taken for occupational deaths. For minor and major injuries, ranges of 420-3400 and 28,000-220,000 ECU/accident respectively are used. With these figures in hand, the monetary costs of occupational health costs could be estimated.

Valuation of employment benefits and local economic impacts. The employment benefits is evaluated by studying the implicit willingness to pay of central government authorities for creating increased employment, revealed through various tax and subsidy schemes. The local employment effects are evaluated by using the implicit subsidy rates per man-year created through average subsidies to firms in local regions.

Valuation of local income effects. The short-term effect on local income is estimated on the basis of the increases in profits of local firms and increases in local public revenues.

Valuation of the impacts of transmission lines on bird populations. The impacts of the transmission lines on bird populations are estimated on the basis of the following information: length and route of the transmission lines, the local bird species, the frequency of bird collisions, and the frequency of bird electrocutions. The economic value of the external costs is estimated based on Contingent Valuation.

3.3 The Methodology for External Cost Assessment for Natural Gas fired Power Generation Fuel Cycles

Volume 4 of the ExternE reports focuses on oil and gas fuel cycles. It defines the stages of a natural gas fuel cycle as including gas exploration, construction and decommissioning of plant and pipelines, extraction, operation of pipelines, gas treatment, power generation, disposal of wastes, transmission of electricity and transport of materials and personnel. It also points out, that for the natural gas to electricity fuel cycle, the most significant externalities are likely to be associated with extraction and power generation (EC, 1995a).

Page 235 to 246 of the ExternE oil and gas report give a full list of all the burdens, receptors and impacts/impact priority degrees of all stages of the natural gas fuel cycle, including gas exploration, the impacts associated with construction and decommission of gas platforms, pipelines, gas treatment facilities, power stations, waste disposal sites and transmission lines, as well as various impacts association with gas-fired power generation. The valuation applied here is based on the ExternE methodology, but conducted in a similar simplified way as for the coal fuel cycle.

3.4 Methodology for the External Cost Assessment of Bio-fuel Cycles

The differences between bio-diesel and fossil fuel are: (1) CO_2 emissions from the combustion stage are not included in the external cost calculation because it is usually assumed that emissions cancel out (at least partly) due to previous fixation of CO_2 by the growing plants. (2) SO_2 emissions from biomass are generally much lower than for other fuel cycles, because of the almost negligible sulphur content in biomass. The most important emissions in all cases are those of ozone precursors, such as NO_x and VOCs. The magnitude of these emissions depends again on the fuel and technology used. (3) Among the burdens and impacts of the upstream stages, the major ones may be the road damages caused by the biomass transport and ecological problems of biomass removal. Biomass transport is a significant stage because of the low density of biomass as fuel. Biomass collection, if not carried out properly, may also imply significant environmental impacts, such as loss of nutrients from the soil or increased erosion.

Table 4. Methodology for Assessing the External Cost of Bio-diesel Fuel Cycle

Cycle Steps	Main Activity		Emissions
Biomass cultivation	Fertilizer use for biomass cultivation	Synthetic fertiliser use Animal manure use	NO_x emissions
	Fossil fuel consumption for farming machines	- Fossil fuel consumption by trucks, tractors etc - Fossil fuel consumption for water pumping - Electricity consumption for water pumping	Air Pollution GHG emissions
	Land use change	Damage to vegetation and trees, changes in bio carbon inventory	
Crude oil production	Crude biomass transport to oil factory	Fossil fuel consumption for transportation	Air Pollution GHG emissions
	Processing at the oil factory	Electricity and fossil fuel consumption Water consumption Wastewater handling	GHG emissions Air pollution Water consumption and pollution
Blending with diesel Combustion	Transport of biodiesel from factory to blending site	Fossil fuel consumption during transport	Air Pollution GHG emissions
	Processing at the biodiesel blending site	Electricity and/or fossil fuel consumption in biodiesel blend production	Air Pollution GHG emissions
Combustion	Transport/power generation		Air Pollution GHG emissions

The methodology on bio-diesel in M7.4 also includes very detailed tables on cost components to be collected and how private and external costs of the bio-diesel fuel cycle should be calculated.

3.5 Methodology for the External Cost Assessment of Hydropower and Wind Fuel Cycles

3.5.1 Hydropower

Hydropower projects do not involve major CO_2 and air pollutant emissions in the process of electricity generation, but have a large variety of environmental and social impacts due to the construction of large dams and alterations to river flows. They can also change the local climate, cause inundation of land and buildings, as well as involve resettlements of local residents.

Table 5. Burdens, receptors, and impacts of the hydropower fuel cycle

Burden	Receptor	Impact
Electricity Generation Phase		
Construction		
Construction roads/road traffic	General public Air quality CO_2 and climate change	Noise Accidents Health effects from air emissions, emissions from motor vehicles
	Wildlife	Disturbed by noise
	Forestry	Improved access to forest areas Loss of future production
Helicopter transport	General public	Noise Health effects from air emissions
	Wildlife	Disturbances from noise
Accidents	Workers	Minor injuries, major injuries, death
Jobs created and increased local income	General public	Local and national employment benefits and local economic effects
Operation		
Flow alteration	Fish	Loss of habitat
	Plants	Loss of habitat
	Birds	Loss of habitat
	Wildlife	Loss of habitat
	Water quality	Eutrophication / acidification
	Agriculture	Loss of grazing area (due to loss of 'natural fence' effect) Loss of source for irrigation
	Waterway transport	Make waterway transport easier or more difficult, congestion, waiting
	General public	Aesthetic effects – cultural and archaeological objects Water falls Loss of area for recreational activities: fishing, bathing, hiking, skiing, hunting Loss of water supply Change in local climate
Impoundment/Dams	Agriculture	Loss of land
	Forestry	Loss of future production

	Aquatic ecosystems	Loss of habitat
	General Public	Reduced recreation Local climate Global warming impact-methane Health impacts from increased mercury concentrations in fish
	Cultural and archaeological objects	Loss of objects
Rock waste disposal sites	General public	Temporarily reduced recreation value due to reduced aesthetic quality of area
	Agriculture	Temporary loss of grazing land
	Forestry	Temporary loss of forest growth
	Terrestrial ecosystems	Loss of habitat
Accidents by operation of the hydropower plant	workers	Minor injuries, major injuries, death
	General public	Minor injuries, major injuries, death
	Infrastructure	Damages to roads, buildings etc
Dam failure	General public	Injuries and death Concerns or psychological pressure about the failure of the dam
	Infrastructure	Damages to roads, buildings etc.
	Land	Flooding of land and loss of production
Jobs created and increased local income	General public	Local and national employment benefits and local economic effects
Transmission		
Construction		
Helicopter transport	General public	Noise
		Health effects from air emissions
	Wildlife and domestic animals	Disturbances from noise
Accidents	Workers	Injuries and deaths
Jobs created and increased local income	General public	Local and national employment benefits and local economic effects
Operation		
Physical presence	Forestry	Lost future production
	General public	Visual intrusion
	Birds	Injury, death
Accidents	General public	Injuries, death
Accidents of maintenance of transmission lines	Workers	Injuries, death
Physical stress	Workers	Musculoskeletal injury
Jobs created and increased local income	General public	Local and national employment benefits and local economic effects

Source: EC, 1995b.

Based on a specific hydropower project in Norway, the ExternE project identifies the following 10 priority impacts to be analyzed for the hydro fuel cycle:

(1) Impacts of flow alteration, impoundment and rock waste disposal sites on agriculture;

(2) Impacts of construction roads, transmission lines, impoundment and rock waste disposal sites on forestry;

(3) Impacts of alteration of river on water supply;

(4) Impacts of waterway transport;

(5) Impact of the construction and operation phase on recreational activities;

(6) Impacts of the construction and operation phases on cultural objects (and objects of archaeological interest);

(7) Impacts of the construction and operation phases on terrestrial and aquatic ecosystems (birds, plants, fish, and wild life loss of habitats, noise in the process of construction and operation).

(8) Impacts of construction on operation on occupational health;

(9) Impacts of construction and operation on local and national employment and local income;

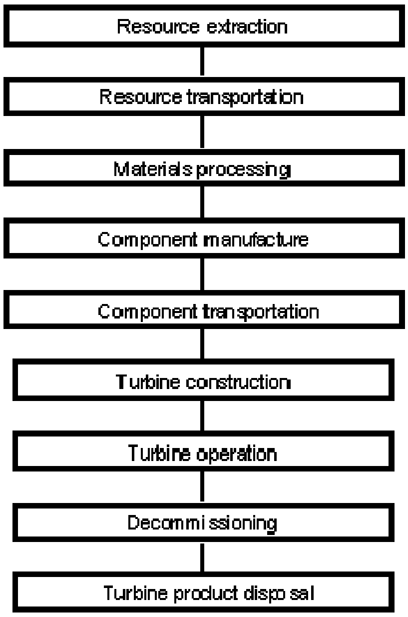
(10) Impacts of transmission lines on bird populations.

It should be noted that the reference project for the impacts listed above is the Sauda Hydroelectric Development Project (SHDP) located in the mountainous area surrounding the small municipality of Sauda. The SHDP project increases electricity generation in the previously developed River Storelv through new water diversions and expansion of two existing reservoirs, combined with diversion projects in six undeveloped areas. In that project, there is no significant submerge and resettlement of local residents. In big hydropower projects which involve submersion of large areas and the resettlement of local residents, the social and environmental impacts are often the most important impacts, which environmental NGOs use as the main reason of objecting the construction of large hydro projects.

3.5.2 Wind

The externality analysis of the wind fuel cycle should cover all impacts and damages caused in the life cycle of a wind turbine, ranging from material extraction, resource transportation and material production, to the manufacturing, transportation, construction, operation and disposal of the wind turbine.

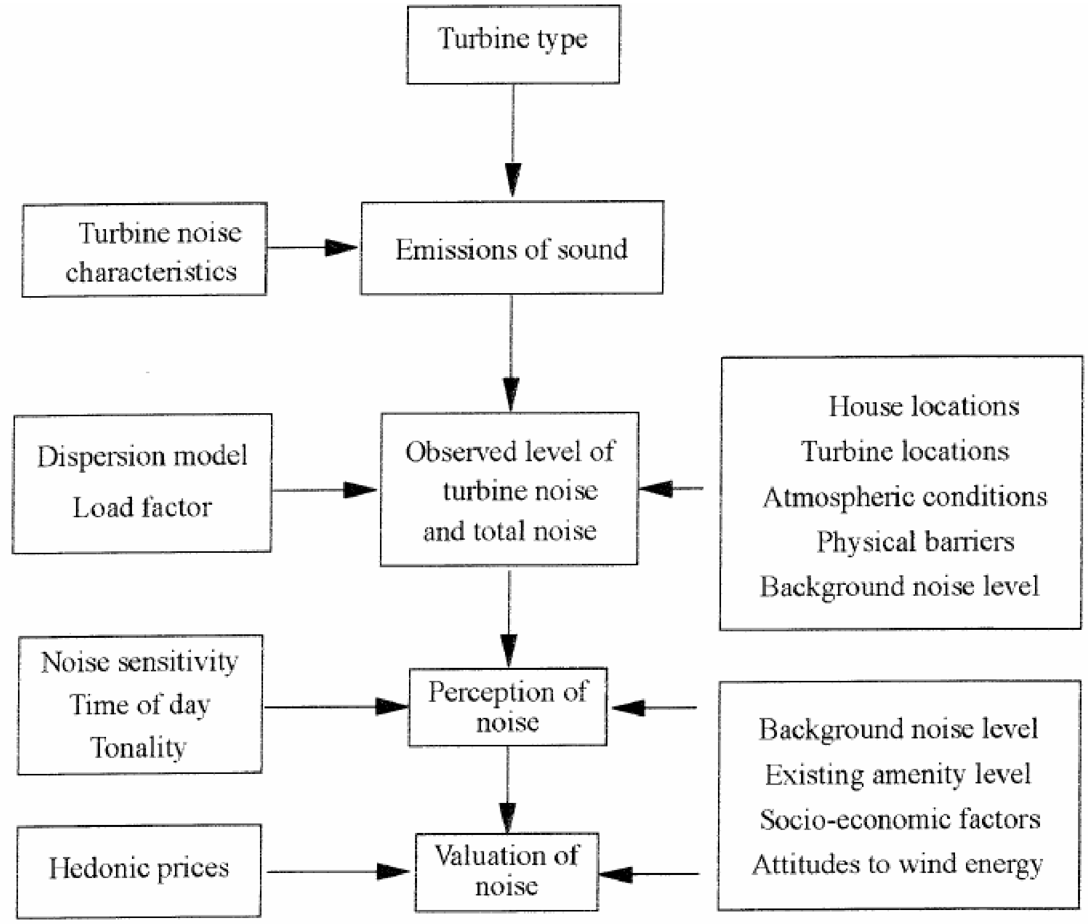
Figure 9. Steps in the Wind Power Fuel Cycle:



Source: ExternE, http://externe.jrc.es/ee9cimage1.htm

For wind power, the main source of energy is the kinetic energy of wind, which is clean and does not involve GHG and air emissions. However, noise emitted during turbine operation is a major environmental impact for the local residents. Under the ExternE approach, the following methodology framework is established for modelling the external costs of noise damage. From Figure 10, it can be seen, that this external cost depends on a range of factors, including the wind turbine type, noise characteristics, time of the day, the location of households, local physical barriers, background noise level, as well as the local people's perception of the noise.

Figure 10. Impact Pathway of Wind Turbine Noise



Source: ExternE Report, Vol. 6, 1995.

3.6 Measures taken to increase the comparability of the country case study results

3.6.1 Converting all the external cost units into Euro

In the country reports, the external costs are expressed in different currencies. Bulgaria has calculated all cost data in Euro, while the Turkish country report only gives the physical amount of various emissions and no cost data. The other three country reports express external costs of different fuel cycles in their domestic currencies, e.g. Chinese Yuan in the Chinese country report, Rupee in the Indian Country Report and USD in the Brazil report.

Exchange Rates Adopted in this Report.

1 € = 10.75 Chinese Yuan

1 € = 58.03 Indian Rupees

1 € = 1.47 US$

3.6.2 Unifying the Marginal Cost of GHG emission

In the country reports, the price or unit cost of each kind of emissions is set based on different criteria or reference. The CASES Project provided two options for estimating the external damage costs of GHG emissions from energy cycles. To increase the comparability of the different country case study results, in this cross-country comparison report, the New NEEDS values, taken from Delivery D5.4. NEEDS; Rs1b. Wp5: MDC_of_GHG_Anthoff_V1.1 is applied for all the country study results.

Table 6. The marginal costs in for greenhouse gases in the base year

GHG	CO_2	CH_4	N_2O	SF_6
Marginal Damage Cost (2005 Euro/ton)	20.66	747.29	27202.90	1290.64

Source: Delivery D5.4. NEEDS; Rs1b. Wp5: MDC_of_GHG_Anthoff_V1.1

Among the five countries, China, India, Turkey, and Brazil only include data for the base year. Bulgaria includes data for 2005, 2010, 2020, and 2030. However, the Bulgarian study only gives the final calculation results in Euros and the calculation process is not well explained from the report.. Due to the fact that Bulgaria also participated in another component of the CASES project, it is assumed that they follow the above guidance on the marginal costs of external damage. Hence, in this report, the Bulgarian external cost data are used as they are given in the country report and no adjustment is made to them based on GHG cost and exchange rate considerations.

4. Comparative Assessment of Coal Fuel Cycles for Bulgaria, China, India and Turkey.

Coal is the most important form of energy input for electricity generation in Bulgaria, China, India and Turkey,, while Brazil is the only one of the five countries where the majority of electricity comes from hydro. Under WP7, the Bulgarian, Chinese, Indian, and Turkish research teams all studied externalities of a national coal fuel cycle. This section will examine and compare the coal fuel cycle case studies done by the 4 country teams and compare and explain the reasons behind their differences and similarities. In this study, the coal fuel cycle is assumed to include both coal and lignite power plants. The Bulgarian country study covers coal and lignite, while the Chinese and Indian focus on coal and the Turkish focuses on lignite.

4.1 The Bulgarian Hard Coal and Lignite Fuel Cycles

4.1.1 Major assumptions and Calculation Results of the Study

The Bulgarian report includes four different coal-to-electricity fuel cycles based on four different kinds of coal-fired power plants: hard coal condensed power plants (Hard Coal CO), hard coal heat and electricity cogeneration power plants (hard coal CHP), lignite condensed power plants (Lignite CO), and lignite heat and electricity cogeneration power plants (Lignite CHP). The Bulgarian case study on fossil fuel based power production technologies are based on existing power plants and the projects for rehabilitation, modernization and construction of new fossil fuel power plants. Table 7 gives an overview of the existing and projected emission data for the four types of coal power plants in the Bulgarian report.

Table 7. Capacity and Operation Parameters of Groups of Power Plants in Bulgaria, 2005-2030

Year	Power Plants	Installed Capacity	Fuel	Capacity Factor	Gene-Ration	Fuel Demand	Emissions				
							SO_2	CO_2	NO_x	PM2.5*	PM10*
		MW	kcal/kg	hours/year	GWh/y	tons	g/kWh			mg/kWh	
2005	Hard Coal CO	1,460	5,714	2,151	3,140	1151493	9.90	1,137	5.11	3.85	77.62
	Hard Coal CHP	500	5,848	2,784	1,392	476,029	24.51	1,081	8.75	3.02	62.82
	Lignite CO	3,040	1,645	3,995	12,144	4,781,405	48.64	1,335	1.91	6.47	79.10
	Lignite CHP	335	1,670	5,967	1,999	866,892	49.01	1,316	1.93	7.31	87.21
2010	Hard Coal CO	1,460	5,714	4,800	7,008	2,568,768	10.05	1140.58	5.11	3.66	67.13
	Hard Coal CHP	500	5,848	4,600	2,300	328,164	18.35	1,327	6.03	3.07	57.10
	Lignite CO	3,530	1,583	5,412	19,105	757,050	44.03	1 355	2.11	11.14	129.61
	Lignite CHP	335	1,610.61	4,803	1,609	303,324	54.15	1,870	2.89	15.34	158.30
2020	Hard Coal CO	1250	5,716	4,709	5,887	2,158,139	9.97	1,139	5.11	3.66	67.26
	Hard Coal CHP	500	5,848	4,600	2,300	750,444	20.03	1,092	7.83	3.13	57.72
	Lignite CO	3,690	1,500	5,386	19,875	7,819,590	5.00	1,326	1.83	5.39	50.00
	Lignite CHP	85	1526.09	4 459	379	186 484	6.00	1 334	1.85	5.57	52.03
2030	Hard Coal CO	1,250	5,716	4,684	5,855	2,146,610	9.96	1,138.60	5.11	3.66	67.27
	Hard Coal CHP	500	5,848	4,600	2,300	750,444	20.03	1,092	7.83	3.13	57.72
	Lignite CO	3,540	1,500	5,674	20,086	7,953,116	5.00	1,324	1.85	5.39	50.00
	Lignite CHP	30	1,516.81	4,200	126	57,960	5.48	1,323	1.86	5.45	50.68

It can be seen from Table 7 that the majority of the coal/lignite generation capacity in Bulgaria is based on lignite CO technology. However, significant capacity is also based on hard coal CO power plants. The table gives a general idea of the pollution burdens of the different coal fuel cycles in Bulgaria and the pollutants included in the table are CO_2, SO_2, NO_x, $PM^{2.5}$ and PM^{10}.

The Bulgarian report gives some background information about the existing hard coal and lignite fired power plants in the country and their future development plans. However, there is no detailed information about the methodologies and data used for the coal fuel cycle analysis. Because 99,8 % of the hard coal used by Bulgarian power plants are imported, the mining and transport stages have only been considered up to the Bulgarian border. For the lignite power plants, significant domestic resources exist within Bulgaria and the upstream fuel cycle stages have therefore been analyzed more thoroughly. The fuel cycle stages included in the total numbers are mining (especially for the lignite plants) and power generation. For the power generation stage emissions of CO_2,SO_2, NO_x and fly ash have been considered. The calculated external costs are shown in Table 8 below. The results are given for each of the four power plant types for the year 2007, 2010, 2015, 2020, and 2030.

Table 8. Results of the Bulgarian Case Study on Coal Fuel Cycles

Year	Coal Power Plant Type	Installed Capacity	Generation	Total Private Cost	External cost	Social Cost
		MW €/Mwhel	GWh/y	€/MWh_{el}	€/MWh_{el}	€/MWh_{el}
2007	Hard Coal CO	3,140	156,731,837	31.94	49.91	81.85
	Hard Coal CHP	1,392	137,755,822	46.70	98.96	145.66
	Lignite CO	12,144	1,785,266,832	35.22	147.01	182.23
	Lignite CHP	1,999	295,901,146	55.39	148.03	203.42
2010	Hard Coal CO	7,008	352,000,132	4.08	50.23	54.31
	Hard Coal CHP	2 300	175 716 710	0.00	76.40	76.40

	Lignite CO	19,105	745,607,026	22.57	39.03	61.60
	Lignite CHP	1,609	249,284,349	0.00	154.93	154.93
2015	Hard Coal CO	6,983	350,690,138	40.07	50.22	90.29
	Hard Coal CHP	2,530	212,621,277	49.73	84.04	133.77
	Lignite CO	18,580	655,748,623	43.84	35.29	79.13
	Lignite CHP	1,079	170,773,703	61.41	158.27	219.68
2020	Hard Coal CO	5,887	294,212,906	43.09	49.98	93.07
	Hard Coal CHP	2,300	193,896,162	51.81	84.30	136.11
	Lignite CO	19,875	567,411,674	46.91	28.55	75.46
	Lignite CHP	253	38,124,549	58.72	150.69	209.41
2030	Hard Coal CO	5,855	292,575,417	46.16	49.97	96.13
	Hard Coal CHP	2,300	193,896,162	53.23	84.30	137.54
	Lignite CO	20,086	574,314,669	50.24	28.59	78.84
	Lignite CHP	0	0	0.00	0.00	0.00

4.1.2 Adjusted results for higher consistency and comparability

The standardized external cost of electricity for the Bulgarian coal/lignite fuel cycles are shown in Table 9 below. These are shown to ease comparison between the different country studies. The external costs are based on the study of Bulgarian hard coal and lignite power plants with CO and CHP technology, shown in the table above. The Bulgarian country team has decided to present the total summarized costs for the four power plant types and hence the numbers have not been broken up into fuel cycle stages or priority pollutants. This also means that it has not been possible to apply the standardized CASES damage value for CO_2. It must be expected, however, that a comparable value has been used by the Bulgarian country team. Since the cost numbers are given in Euros by the Bulgarian country team, no currency conversions have been made.

Table 9. External costs of electricity for the Bulgarian coal fuel cycle

Stage	Plant type	Unit	Total cost
Power generation	Hard Coal CO	€ cent/kWh	4.99
	Hard Coal CHP	€ cent/kWh	9.90
	Lignite CO	€ cent/kWh	14.70
	Lignite CHP	€ cent/kW	14.8

It can be seen from Table 9, that the external costs from power generation by hard coal are significantly lower than by lignite. For hard coal power generation, the external costs are almost twice as high for a plant with CHP, than a standard plant. For lignite-based power generation, the cost difference between CO and CHP is almost negligible.

4.2 The China Coal Fuel Cycle Case Study

4.2.1 Major assumptions and calculation results of the study

The Chinese country team estimate the externalities of the coal fuel cycle in two different studies - on a cost per ton coal and a costs per kWh basis.

Cost per ton coal analysis

For the analysis of the external cost per ton of coal, the Chinese team bases their study on the following equation:

EC=Em+Ew+Et+Ecom

- where *EC* is the total environmental cost for coal, *Em* is the environmental cost of coal mining, *Ew* is the environmental cost of coal washing, *Et* is the environmental cost of coal transport, *Ecom* is the environmental cost from coal combustion.

When applied in practice, the Chinese team changes the equation so that the actual calculation appears as shown below:

EC = 50.45 (pollution from mining) +65.4 (SO2 emissions from combustion) +27.8 (PM emissions from combustion) +4.4 (stockpiling) +0.5 (water for washing) = 148.55 RMB/ton of coal.

The mining cost of 50.45 Yuan/ton is based on the Shanxi Case Study that considers the environmental costs from coal mining including eco-system damage. The detailed costs of the different parameters are shown in Table 10 below.

Table 10. The Ecosystem Cost of Coal Mining in Shanxi Case Study

Ecological loss item	Economy loss (million yuan)	Ecological loss per ton coal(yuan per ton coal)
Loss of permanent destruction of water resource caused by mining	8677	19.30
Loss of water shortage caused by mining	31	0.07
Soil and water loss caused by mining	330	0.74
Loss of forest resource growth	90	0.20
Loss of mining occupying land	1327	2.95
Loss of decreasing releasing oxygen quantity caused by mining	3697	8.22
Loss of descendant water-holding function caused by vegetation destruction	131	0.29
Destructed land reclamation expense	216	0.48
Biodiversity loss due to expanding pitprop	4979	11.08
Increased cost of vegetation's restoration and reconstruction	23	0.05
Loss of wetland ecosystem	350	0.78
Loss of species resource	1245	2.77
Mining subsidence reclamation	970	2.16
Change from irrigated land to dry land	49	0.11
Building loss	525	1.17
Traffic installation loss	36	0.08
Total	22677	50.45

The cost of 65.4 yuan/ton is the environmental cost of SO_2 emissions from coal combustion. Here, the Chinese team have used data from the Chinese State Environment Administration, showing that of a total loss from SO_2 emissions in 2003 of 110 billion yuan, coal accounted for 103.4 billion. Total coal use in 2003 was 1.58 billion ton and hence the environmental cost for SO_2 emissions can be calculated to 65.4yuan/ton of coal use. The argument is that in 2003, 94% of the SO_2 emission and 28% (mid value of the 3.5% to 41% range) of the PM emission is due to coal combustion. The source of this data is not indicated in the Chinese country report.

The 27.8 yuan/t coal is the environmental cost of PM emissions from coal combustion. This cost is estimated on the basis of the emission charges set by the Chinese government.

The 4.4yuan/ton of coal is the external cost of stockpiling of waste, treatment of coal mine waste and waste fires. The environmental cost for coal washing is given by the price of re-processing of waste water, which is 0.5yuan/m^3 or 0.5yuan/t coal (taking average fresh water use 1m^3/t).

Cost per kWh analysis

In this analysis, a power plant with a capacity of 100MW, annual plant load of 6000h and annual power generation of 6 billion kWh is used. The heat value of the crude coal is 16.74 J/kg, the ash content is 15%, the efficiency of the electrostatic dust removal is 99% and the power plant efficiency is 35%. On-site electricity use amounts to 5% of the total generation.

The calculated external costs from the power generation stage are shown in the Table 11 below. The costs are calculated based on the emission rates from the power plant mentioned above. The prices used for valuating the externalities from the priority burdens are based on Chinese Pollutants Charge Standards (PCS) and US Environmental Value Standard numbers (US EVS).

Table 11. The External Costs of Coal Combustion for Electricity, based on the Level of National Emission Charges

Pollutant	Standard of National Emission charge (RMB/kg)	Pollutants emission from coal combustion (g/kWh)	Environmental Costs (0.01 RMB/kWh)
SO_2	6.000	8.461	5.050
NO_x	8.000	3.792	3.326
CO	0.023	0.122	0.012
CO_2	1.000	816.640	1.878
Suspended particles	2.200	0.189	0.041
Powdered Coal ash	0.120	51.947	0.623
Furnace Dust	0.100	14.210	0.142
Total			11.072

Source: Jiang et al, 2007, the China Coal Fuel Cycle Report under WP7

4.2.2 Adjusted results for higher consistency and comparability

To facilitate comparison between the country studies, the results from the Chinese cost/kWh analysis are adjusted to the CASES standard format. The damage cost of CO_2 is changed using the agreed CASES value of 20.66 €/ton. This cost can be applied to all country studies since climate change is global in nature and therefore so is the subsequent damage costs. The costs of the other priority pollutants are based on the specific Chinese values. The calculated damage costs are converted from Chinese Yuan to Euro using the conversion factor from December 2007 of 0.0930 €/Yuan. The results are shown in Table 12 below.

Table 12. External costs of electricity for the Chinese coal fuel cycle.

	Unit	CO_2	SPM	SO_2	NO_x	CO	Ash	Dust	Total cost
Stages combined	g/kwh	816.64	0.189	8.416	3.792	0.122	51.947	14.21	
	€ cent/kWh	1.69	0.004	0.47	0.309	0.001	0.058	0.013	2.54

From Table 12 it can be seen that the major external costs from the Chinese coal fuel cycle are caused by CO_2 emissions followed by emissions of SO_2 and NO_x. The total damage costs are calculated to be 2.54 € cent/kWh.

4.3 The Indian Coal Fuel Cycle Case Study

4.3.1 Major assumptions and calculation results of the study

The Indian country study includes most major fuel cycle stages, namely, mining, coal transport, coal beneficiation and power generation/transmission. The external costs are calculated based on a case study using Indian power sector conditions and the main assumptions are given in Table 13 below.

Table 13. Assumptions in the Indian Coal Fuel Cycle Case Study

Indicator	Assumption
Coal used per kWh power generation (average)	0.7 kg/kWh
Diesel used to carry 1 ton coal for 1 km by railways	49.37 ml/ton coal transported for 1 km
So CO_2 emitted per ton of coal transported	0.131 gms CO_2/kg coal transported for 1 km
So SO_2 emitted per ton of coal transported	0.00082gms SO_2/kg coal transported for 1 km
So NO_x emitted per ton of coal transported	0.00147gms NO_x/kg coal transported for 1 km
Average coal transported for power generation	617 km
Coal Mining uses energy for mining and water	which results in around 2g CO_2/kwh
Coal transported from mines to power plants results	57g CO_2 / kWh
Ash disposal emissions	14g CO_2 / kWh
Per cent coal produced used for power generation	70%
Average % of ash content in Indian coal	40%
Average ash disposal km	75 km

Average load taken by truck	7.5 ton
Fuel efficiency of truck	5 km per litre
Cost of water	0.0005 Rs./ml

Based on the assumptions in Table 13, the Indian team modelled the external costs for 6 out of the 7 major steps in the coal fuel cycle. The facilities construction/ decommissioning stage has not quantified, but since a coal power plant generally has a lifetime of several decades, the external costs of this step is small and ignorable. Table 14 shows the calculated priority burdens for the different fuel cycle stages.

Table 14. Environment impact assessment of the different steps in coal fuel cycle in India

Stages	Air Pollution										
	GHG			Local							
	gCO2/kWh	g CH4/kWh	g RPM/ kwh	g SPM/kWh	g SO2/kWh	g NOx/kWh	gSS/kWh	gCOD/kWh	g BOD/kWh	gO&G/kWh	ww ml/kWh
Coal mining	2	0.10	0.079	0.200	0.013	0.007	0.029	0.044	0.006	0.025	0.038
Coal beneficiation	0.5				0.003	0.002					2113.067
Coal Transport	57				0.353	0.634	-	-	-	-	
Power generation	1307.67			0.280	7.48	4.09					0.725
Ash Disposal	1.49	0.001		0.0045	0.01	20.13	-	-	-	-	
Ash generation			1.05								

Then Indian country study monetises the various impacts of the priority burdens and the calculated external costs are shown in Table 15. The valuation of the damage from SO_2 and NOx emissions has been done using prices from the US market while valuation of damage from SPM has been based on an Indian study of human health impacts. The damage costs of GHG emissions are based on prices from the European carbon market and the cost of water is based on the water price for industrial consumers in India. The study uses a conversion factor of 1 USD = 40 Indian Rupees when converting US damage costs to Indian Rupees.

Table 15. Monetization of Impacts in the Fuel Life Cycle of Coal for Power Generation

Stages	Air Pollution						Water Pollution	
	GHG		Local					
	Rs CO2/kWh	Rs CH4/kWh	Rs RPM/ kwh	Rs SPM/kWh	Rs SO2/kWh	Rs NOx/kWh	Rs. Ww/kwh	
Coal mining	0.00057	0.000	0.000	0.001759	0.00070	0.00009	0.000019	
Coal beneficiation	0.00014			0.000440	0.00018	0.00002	1.056534	
Coal Transport	0.01605			0.025797	0.01032	0.00129		
Power generation	0.37072			1.150	0.46000	0.05750	0.000363	
Ash Disposal	0.00042			0.001307	0.00052	0.00007		
Ash generation								
Slurry								
Total - Rs/kwh	**0.38791**			**1.17930**	**0.47172**	**0.05897**	**1.05692**	**3.15**

4.3.2 Adjusted results for higher consistency and comparability

The priority pollutants included in the Indian country study are CO_2, CH_4, RPM (Respiratory Particulate Matter) SPM (Suspended Particulate Matter), SO_2, NO_x and water pollution. The damage costs of CO_2 and CH_4 have been adjusted using the CASES standard values of 20.66 €/ton CO_2 and 747.29 €/ton CH_4 to facilitate cross-country comparison. The damage costs for SO_2 and NO_x based on US market prices continue to be used. The Indian cost numbers have been converted to Euros using a conversion factor from December 2007 of 0.017 €/Rs. The results are shown in Table16 below.

Table 16. External costs of electricity for the Indian coal fuel cycle.

Stage	Unit	CO_2	CH_4	RPM	SPM	SO_2	NO_x	Water*	Total cost
Mining	g/kwh	2	0.511	0.079	0.200	0.013	0.007	0.038	
	€ cent/kW	0.004	0.038	0	0.003	0	0	0	**0.045**
Beneficiation	g/kwh	0.5	-	-	-	0.003	0.002	2113	
	€ cent/kW	0.001		-	0	0	0	0.18	**0.181**
Transport	g/kwh	57	-	-	-	0.353	0.634	-	
	€ cent/kWh	0.118		-	0.045	0.016	0.074	-	**0.253**
Power generation	g/kwh	1307.67	-	-	0.280	7.48	4.09	0.725	
	€ cent/kWh	2.70		-	1.98	0.33	0.48	0	**5.49**
Ash disposal	g/kwh	1.49	0.001	-	0.0045	0.01	0.02	-	
	€ cent/kWh	0.003	0	-	0.002	0	0.002	-	**0.007**
All stages	g/kwh	1368.66	0.512	0.079	0.4845	7.859	4.753	2113.763	
	€ cent/kWh	2.826	0.038	0	2.03	0.346	0.556	0.18	**5.976**

* Water is given in ml/kWh

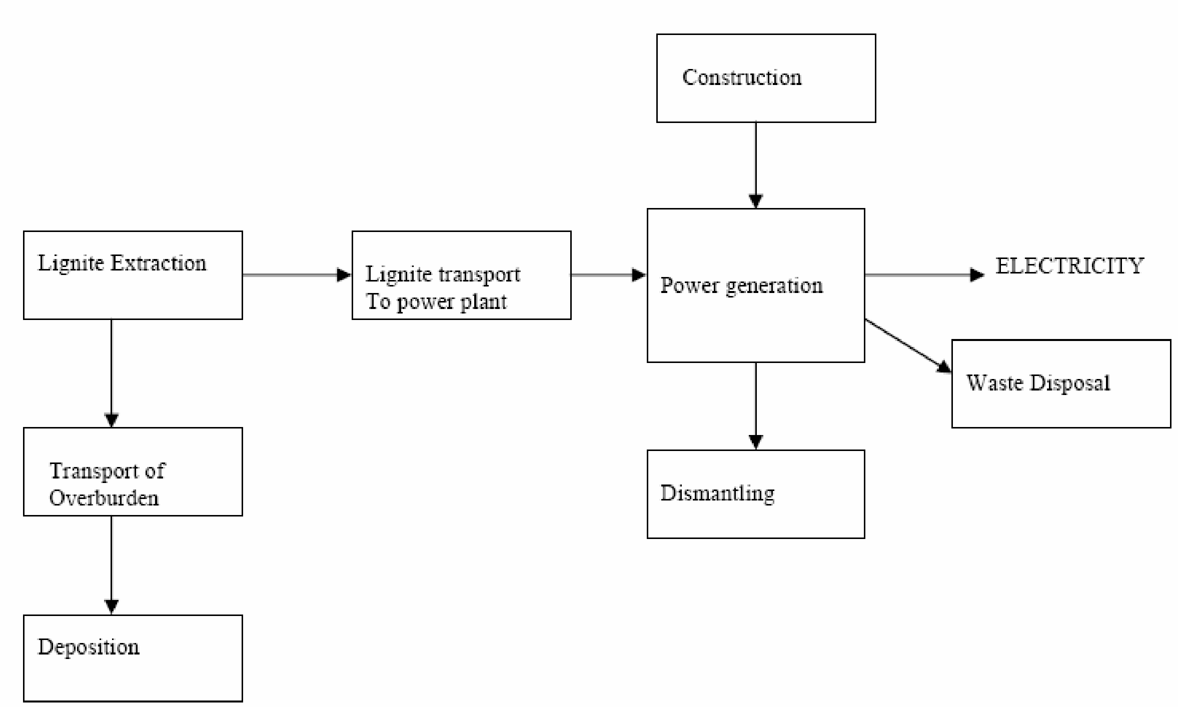
It can be seen from Table 16, that the major external costs from the Indian coal fuel cycle are caused by the power generation stage. Here CO_2 emissions account for the largest damage costs followed by SPM and NO_x. The damage costs from SO_2 emissions are relatively low and this might be explained by the lower sulphur content of Indian coal. The transport stage is the second largest contributor with the main damage from CO_2 emissions and after that comes the coal beneficiation stage. Here water use accounts for the main externality. The impacts from coal mining and ash disposal are relatively small compared to the other fuel cycle externalities. The total external cost of the Indian coal fuel cycle is calculated to 5.976 € cent/kWh.

4.4 The Turkish Lignite Fuel Cycle Case Study

4.4.1 Major assumptions and calculation results of the study

The lignite fuel cycle as defined in the Turkish case study consists of 5 stages: (1) lignite extraction; (2) transportation of the lignite to the power plant; (3) operation of the power plant; (4) construction and dismantling of the power plant and (5) waste disposal. The stages are shown in Figure 11 below.

Figure 11. Stages of Lignite Fuel Cycle as Defined in the Turkish Report



The Turkish country study is based on a lignite power plant fuelled with domestic lignite. The characteristics of the lignite used for power generation is shown in Table 17.

Table 17. The major characteristics of the Yeniköy Basin lignite

	Humidity (%)	Ash (%)	Volatile matter (%)	sulphur (%)	Calorific Value (kcal/kg)
SEKKÖY	31.60	25.48	29.9	1.2	1,970
_K_ZKÖY	29.04	25.63	28.4	2.0	2,303
HÜSAMLAR	30,17	34,25	22.4	1.2	1.607

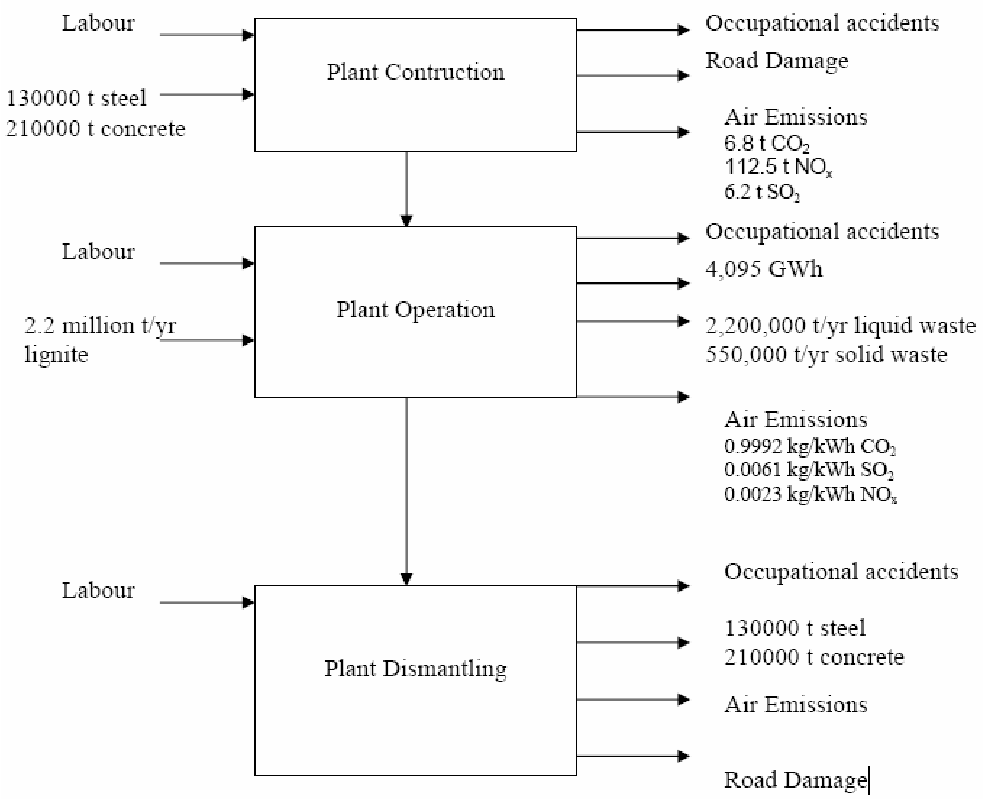
The lignite is, after extraction, transported 8 km to the power plant by conveyor belts. Overburdens from the lignite extraction are transported about 4 km to a dumpsite largely by truck. The main operational parameters of the reference power plant are shown in Table 18 below.

Table 18. Capacity and Operation parameters of the reference power plant

Capacity and Operation parameters	
Location	Milas-MUGLA
Number of Units	3
Installed Capacity	630 MW
Annual production capacity (theoretical)	5,518,000.000 kWh
Nominal production capacity	4,095,000,000 kWh
Annual main fuel demand	5,700,000 tones(1750kcal/kg)
Net efficiency	37%
Technical Data	
Stack height	310 m
Stack diameter	5 m
Lignite requirement	21,000 tones/day
Fuel oil No:6 requirement	10,000 tones/year
Emissions	
CO_2 kg/kWh	0.99929
SO_2 kg/kWh	0.00608
NO_x kg/kWh	0.00005
TPS kg/kWh	0.00022
Characteristics of the lignite used in the power plant	
Lower Heating Value (kcal/kg)	1750 ± 200
Ash content (%)	27.56
Humidity (%)	35.90
Total Sulphur (%)	2.70

Unlike the Chinese team, which totally neglects the external costs from power plant construction/decommissioning and the India Team that analyzes it non-quantitatively, the Turkey team gives detailed data about the various external costs during the construction and dismantling of coal power plant as shown in Figure 12.

Figure 12. Results of the Turkey Lignite Study



Moreover, in the Turkish case study, special importance is attached to external impacts due to steel and concrete transportation during the construction and disposal of the power plant. The material flows are shown in Table 19.

Table 19. Construction materials and transportation

Material	Amount	Transport-railway	Transport-truck	Transport-distance	Transport Load (t*km)
Steel	130000 t	80%	20%	180	$23.4x10^6$
Concrete	210000 t	100%	-	70	$14.7x10^6$

The Turkish country study does not, however, give emission data for the parameters mentioned above and generally it does not monetise any of the externalities analyzed. Although the report gives a description of the local climate, geography, population, and land use circumstances, the external costs associated with water pollution, land damage, public health impact, as well as eco-system impacts are not quantified.

4.4.2 Adjusted results for higher consistency and comparability

The Turkish country study places the main focus on quantifying the externalities from the transport and power generation stages. The priority pollutants included are CO_2, SPM, SO_2 and NO_x and in addition different kinds of waste have been quantified. The impacts have not been monetized, however. Therefore it has been decided to evaluate the impacts from the main burdens based on results from the UK part of the ExternE project. Since the damage cost of a specific burden varies for different countries, the costs can be adjusted to Turkish conditions using the relationship between the UK and

Turkish PPP GNI per capita. The UK GNP PPP for 2003 is $ 31430 while the Turkish is $ 7720 and the conversion factor applied to the UK external costs can therefore be calculated to 0.246. The calculated external costs are shown in Table 20 below. The NO_x emissions from transport have not been included in the final number since they seem to be too high compared with other studies.

Table 20. Adjusted Results of the Turkey Coal Cycle Case Study

Stage	Unit	CO_2	SPM	SO_2	NO_x	Total cost
Transport	g/kwh	32.23	-	0.02	(66.42)	
	€ cent/kWh	0.067	-	0.003	(5.39)	**0.07**
Power generation	g/kwh	999.3	0.22	6.08	2.25	
	€ cent/kWh	2.065	0.079	0.953	0.182	**3.279**
All stages						**3.35**

It can be seen from Table 20, that the power generation stage is responsible for a significant fraction of the external costs and the main damage is caused by emission of CO_2 and SO_2. Emissions of NO_x and SPM (Suspended Particulate Matter) have a smaller impact. If the NO_x emissions from the transport stage are excluded, the damage from transport seems to be small. However, since the NOx emissions data appear questionable, the damage costs from the transport stage are surrounded with some uncertainty. The total external cost from the coal fuel cycle stages assessed is 3.35 € cent/kWh.

4.5 Comparison and Analysis

From the results above it can be seen that the external costs of the coal fuel cycle for the different countries considered are in similar magnitude but varies considerably. The highest costs are exhibited by the Bulgarian lignite power plants with external costs of almost 15 € cent/kWh. These are followed by the Bulgarian hard coal power plant with CHP, with an external cost of 9.9 cent/kWh. The Indian coal fuel cycle has an external cost of 5.076 € cent/kWh, which is slightly higher than of the Bulgarian hard coal CO of 4.99 € cent/kWh. The external cost of the Turkish lignite fuel cycle is somewhat lower, namely 3.35 € cent/kWh, while the external cost of the Chinese coal fuel cycle is as low as 2.54 € cent/kWh. As mentioned earlier in the chapter, some studies have only quantified one or two fuel cycle stages while others have included almost all stages. The relatively high external costs for the Indian coal fuel cycle might therefore be partly explained by the inclusion of most stages, while the lower cost for the Turkish fuel cycle can be somewhat explained by the inclusion of only two stages. Since the power generation stage is responsible for the main externalities of the coal fuel cycle, however, the inclusion of different upstream stages should only result in smaller differences between the studies.

Since the same value for CO_2 has been applied for China, India, and Turkey, the external costs for CO_2 should be readily comparable. It has not been possible to change the value for CO_2 for the Bulgarian case and hence, the Bulgarian costs cannot be directly compared with the other country studies. For the other priority pollutants different approaches for valuation have been applied and the cost estimates for the different studies are therefore associated with some inconsistency. One should therefore be careful when comparing the different cost results.

5. Comparative Assessment of Natural Gas Fuel Cycle Studies for Brazil, Bulgaria and China.

Three out of the five countries, namely Brazil, Bulgaria and China have analyzed the natural gas fuel cycles under WP7. The Chinese case study focus on the GHG and air pollutant emissions, the Brazilian study focuses on the health impacts, while the Bulgarian study gives a total damage value.

5.1 The Brazilian Natural Gas Fuel Cycle Case Study

5.1.1 Major assumptions and calculation results of the study

The Brazilian country study identifies the following main sets of impacts on human health as being of greatest relevance for the Brazilian natural gas fuel cycle:

1) Impacts of plant construction and operation phases of occupational health;

(2) Impacts of GHG emissions (CO_2, CH_4 and N_2O) from gas platforms (extraction and operation) and energy generation; and

(3) Impacts of atmospheric emissions from the energy generation phase on human health

The external costs from the Brazilian natural gas fuel cycle has been calculated based on a thermo electric generation complex consisting of both single and combined cycle power plants. The total capacity of the complex is 1355 MW. The valuated impacts are from the power generation stage and priority burdens include CO_2, N_2O and NO_x emissions. The external cost of NO_x has been calculated as the damage costs to human heath from wet deposition in an area around the power generation complex. The cost of nitrate deposition has been calculated to US $61 890 084 in 2005 values, which is equivalent (also at the value for same year) to an additional cost of around US $5.23/ MWh generated.

5.1.2 Adjusted results for higher consistency and comparability

The external costs for the Brazilian natural gas fuel cycle used here have been estimated for the power generation stage of a combined cycle power plant. The priority burdens included are CO_2, N_2O and NO_x. The CO_2 and N_2O damage have been monetized using the standard CASES values of 20.66 €/ton CO_2 and 27202.9 €/ton N_2O. The damage cost of nitrates has been converted from US$ to Euros using a conversion factor from December 2007 of 0.68 €/$. The results are shown in Table 21 below.

Table 21. Brazilian natural gas fuel cycle

Stage	Unit	CO_2	N_2O	Nitrates	Total cost
Power generation	g/kwh	393.0	0.013	0.71	
	€ cents/kWh	0.81	0.035	0.35	1.20

As shown in Table 21, the main external costs are caused by CO_2 emissions followed by wet deposition of nitrates. The total external cost is calculated to 1.20 € cent/kWh.

5. 2 The Bulgarian Natural Gas Fuel Cycle Case Study

5.2.1 Major assumptions and calculation results of the study

Bulgaria imports almost 100% of its natural gas from Russia and the external costs of the extraction and transportation stages have therefore only been included to the border of Bulgaria. Due to the lack of direct information about gas transportation costs the externalities of the Bulgarian natural gas fuel cycle are in reality only estimated for the power generation stage. The main natural gas power plants used in Bulgaria are CHP plants and the total installed capacity is currently 907 MW. In this analysis, the focus is also on natural gas power plants based on CHP technology. Table 22 shows the capacity and operating parameters of Bulgarian CHP natural gas power plants in 2005 and expected future developments.

Table 22. Capacity and Operation Parameters of the Existing and Future Gas CHP Power Plants

	Installed Capacity	Fuel quality	Capacity Factor	Gene-ration	Fuel Demand	Emissions				
						SO_2	CO_2	NO_x	$PM^{2.5}$*	PM^{10}*
	MW	kcal/m3	Hours/year	GWh/y	m3	g/kWh			mg/kWh	
2005-Existing	907	7300	2595	2354	639984	9.22	650	4.49	3.43	10.08
2010-Reference	895	7310.28	4094	3665	285980	10.18	868	8.54	6.82	21.09
2020-Reference	1165	7446.95	4109	4787	1267128	9.16	598	3.87	2.62	7.40
2030-Reference	1185	7454.6	4107	4867	1283768	9.16	598	3.87	2.62	7.40

The Bulgarian report does not include any detailed information on the assumptions and procedures for the calculation process. Therefore, the calculation procedures have not been elaborated further in this report. However, the Bulgarian report mentions that it has been produced in connection with the Bulgarian team's activities under WP2 and WR 4 of the CASES project. The table below shows the calculated cost parameters for the Bulgarian natural gas study.

Table 24. Private, external and social costs for Gas CHP Power Plants

	Generation (GWh/y)	Total Health Cost (€/y)	Total Private Cost (€/MWh$_{el}$)	External Cost (€/MWh$_{el}$)	Total Social Cost (€/MWh$_{el}$)
2007	2,354	95,611,936	52.38	40.62	92.99
2010	3,665	147,327,828	0.00	40.20	40.20
2015	4,295	169,336,393	59.48	39.43	98.91
2020	4,787	184,281,395	62.86	38.50	101.36
2030	4,867	186,621,656	66.03	38.35	104.38

5.2.2 Adjusted results for higher consistency and comparability

The Bulgarian country study has focused on a CHP natural gas power plant. Since all natural gas used in Bulgaria is imported from Russia, the external costs of upstream processes have only been included to the Bulgarian border. This means that the gas exploitation stage has not been covered and the main focus for the Bulgarian country study is the power generation stage. The Bulgarian team has not broken the case study results up into different stages, but gives the external cost as a total number for the gas fuel cycle. It has therefore not been possible to change the damage costs for

GHG emissions using the standard CASES value. The Bulgarian country study gives the number in Euros and therefore no currency conversions have been made.

Table 25. Bulgarian natural gas fuel cycle

Stage	Unit	Total cost
Power generation	€ Cent/kWh	4.062

5.3 Chinese Natural Gas Fuel Cycle Case Study

5.3.1 Major assumptions and calculation results of the study

The Chinese natural gas study both includes an analysis of the size of the burdens from the different fuel cycle stages and an examination of the external costs for a power generation case study.

Burden size analysis

Table 26 below shows the size of the priority burdens of a natural gas fuel cycle for a natural gas flow of 1000 m^3. The study does not make explicit the detailed technical parameter assumptions. Instead, it directly uses the emission estimates of a detailed case study by Dong et al. of 10 gas wells with a capacity of 550,000m^3/day each.

Table 26. Analysis list of natural gas lifecycle emissions

		Exploitation stage	**Transportation stage**	**Utilization stage**	**Total**
Waste gas	CO_2 (kg)	232.6		1440	1672.6
	SO_2 (kg)	0.415		0	0.415
	H_2S (kg)			0	0
	NO_X (kg)	0.159	0.087	2.734	2.98
	CH_4 (kg)	0.295	0.006	0.144	0.445
	CO (kg)	0.015	0.003	1.312	1.33
Waste water		0.15	0.006	2.607	2.763
Solid waste	Waste residuals (kg)	6.4		—	6.4
	Rock debris (kg)	6.814		—	6.814
	Sewage (kg)	0.007		—	0.007

External cost analysis

The analysis of the external costs of the natural gas fuel cycle focuses on the priority burdens from the power generation stage. The calculations are based on a 100 MW natural gas power plant with an annual power generation of 6 billion kWh. The heat value of natural gas is set to 36 MJ/m^3. The results of the case study are given in Table 27 below. The valuation of the priority burdens are based on Chinese and US government charges on emissions, obtained from China Pollutants Charge Standard (PCS) and the U.S. Environmental Value Standard (US EVS). The same results are shown in Table 28, but on a per volume natural gas basis.

Table 27. The External Costs of the Natural Gas Fuel Cycle in RMB/kWh.

Pollutant	Standard of National Emission charge (RMB/kg)	Emission (g/kWh)	Environmental Costs (0.01RMB/kg)
SO_2	6.000	0.023	0.001
CO_2	0.023	402.000	0.925
Nox	8.000	1.240	0.992
Suspended particles	2.200	0.047	0.010
Total			1.928

Table 28. The External Costs of the Natural Gas Fuel Cycle in RMB/m3.

Pollutant	Standard of National Emission charge (RMB/kg)	Pollutants emission from Natural Gas combustion (kg/m3)	Environmental Costs (RMB/M3)
SO_2	6.000	0.000415	0.0025
CO_2	0.023	2.242	0.05156
Nox	8.000	0.00298 (low)	0.0238 (low)
		0.0062 (high)	0.0496 (high)
CH_4	0.483	0.000445	0.00021
Suspended particles	2.200		
Waste Water	0.5 RMB/ton	0.0028 (ton)	0.0014
Total	0.079491 RMB/m3 (low NO_x) 0.105251/m3 (high NO_x)		

Source: Jiang et al, 2007, the China Natural Gas Fuel Cycle Report under WP7

5.3.2 Adjusted results for higher consistency and comparability

The externalities of the Chinese natural gas fuel cycle are given, as in the case of the coal fuel cycle, for the power generation stage for the priority pollutants. The priority pollutants included are CO_2, SPM, SO_2, NO_x and CO. The damage costs for CO_2 has been adjusted using the CASES standard value of 20.66 €/ton. The costs of the other pollutants are based on Chinese and US standard pollution charges. The costs are converted from Chinese Yuan to Euros using the conversion factor from December 2007 of 0.0930 €/Yuan. The results are shown in Table 29 below.

Table 29. Chinese natural gas fuel cycle

Stage	Unit	CO_2	SPM	SO_2	NO_x	CO	Total cost
Power generation	g/kwh	402.0	0.047	0.023	1.240	-	
	€ cent/kWh	0.83	-	0	0.092	0.001	0.92

As can be seen in Table 29, the major external cost arises from CO_2 emissions while a smaller contribution is due to emissions of NO_x. The external costs of the other priority pollutants remain marginal.

5.4 Comparison and Analysis

In all thee studies of the natural gas fuel cycle, only the power generation stage has been quantified in monetary values. This means that in terms of fuel cycle stages covered, the results of the studies are comparable. In the Brazilian and Chinese studies CO_2 emissions have been adjusted using standard CASES damage values while it has not been possible to adjust the Bulgarian number. This means that the damage costs from CO_2 emissions are comparable for the Brazilian and Chinese country studies, while it is unknown what value has been applied in the Bulgarian study. The size of the external costs is quite similar for the Brazilian and Chinese country studies while it is several times higher for the Bulgarian study. Since the Bulgarian report does not give any information of the calculation procedures it is difficult to point to some specific parameters influencing this difference.

6. Comparative Assessment of the Hydropower Fuel Cycle Studies of Brazil and Bulgaria

6.1 The Brazilian Hydropower Fuel Cycle Case Study

6.1.1 Major assumptions and calculation results of the Study

The Brazil hydropower life-cycle external cost study focuses on the health impacts. It quantifies the health impacts including the following two components:

- Impact of the construction phases resulting from the significant increase in the population;
- Impacts of the operation phase as a result of the increase in water-borne diseases and the increase in infectious disease and parasite vectors due to the changes in the water regime and the synergy with the increase in the population.

Major assumptions

The construction of a hydro power plant leads to an increase in the local population and a subsequent increase in the state public health expenditures and public expenditures on sanitation. The public expenditures on sanitation include investments for expanding water supply, sanitary sewage and solid waste facilities.

The cost of mortality and morbidity

The morbidity value resulting from diseases is estimated using the Disease Cost Method (DC), which takes into account, as shown below, medical expenditures from the treatment of diseases and the value of work days lost as the result of the disease.

DC Total = expenditure on treatment + value of work days lost

Statistical Value of Life

In the Brazilian case study, the statistical value of life is calculated based on the European statistical value of life for in 1998 ($3,250,000.00, in 1992 $), per capita GDP, the parity of purchasing power, life expectancy, as well as health expenditures. The value is calculated to US$ 929,743.75.

Increase in vector-borne diseases

The Brazilian case study takes into account the morbidity values for VTDs (vector transmissible diseases) which are *schistosomiasis mansoni* (gastropods), yellow fever, malaria, leishmaniasis, dengue fever, filariasis, chagas disease and onchocerciasis (insects). These are caused by the increase in vectors due to the construction of dams. Also included are water-borne diseases (WBD) resulting from alterations in flows (reservoir) in the construction of a hydro-electric plant, which are: cholera, typhoid fever, dysenteries and internal parasites and infectious diarrhoea (low levels of hygiene). The impacts of the vector-borne diseases are valued based on the number of patients, the length of hospitalisation and the cost of treatment (data from local hospitals and local health statistics).

Increase in water-borne disease (avoided costs)

Due to some recent legislation, such as the Epidemiological Control Program and the Intensification of Endemic Controls Program, hydropower plant constructors are required to implement some measures and programs to mitigate increases in diseases from the construction of hydro projects. The legislation recommends that implementation of these programs should begin a year before construction is started. This part of the costs is included in the hydropower construction costs (private cost).

In the Brazilian case study, the avoided costs related to the increase in water borne diseases is calculated as the avoided increase in incidences of some epidemic diseases due to the construction of the hydro power plant. This part of the external costs is calculated based on three kinds of diseases with highest incidences in the region: leishmaniasis, dengue fever, and malaria. The equations used for the calculations are shown below.

Formula:

Increase in water-borne disease (avoided costs) = Avoided costs of leishmaniasis + avoided costs of dengue fever + avoided cost of malaria

Avoided leishmaniasis costs = incidence of leishmaniasis * Disease cost of each case * increase in population due to the hydro project

Avoided costs of dengue fever = Incidence of dengue fever * Disease cost of each case * increase in population due to the hydro project

Avoided cost of malaria = incidence of malaria * Disease cost of each case * increase in population due to the hydro project

Results

For hydroelectric generation a case study was prepared related to the implementation of the Rio Madeira Complex in Rondônia in the Amazon region. The complex is composed of two hydroelectric plants, with a total capacity of 6500 MW and is planned to enter into operation in 2012. In addition to the Rio Madeira case study, two studies carried out by Reis (2001) are also presented: One for the Tucuruí plant (4000 MW), constructed between 1975 and 1984 in the Amazon region and expanded to 4375 MW in 2005 and one for the Serra da Mesa plant (1275 MW), which commenced operations in 1998 and is located in the Cerrado region. These plants are all located in regions of low population density, but with a propensity to endemics if these are not controlled. The Tucuruí plant was constructed at a time with lack of stringent environmental legislation and hence few external costs were included in the private costs. The Serra da Mesa plant was constructed in compliance with more restrictive environmental legislation and Rio Madeira, has to fulfil modern environmental standards. Therefore the results of the three case studies represent different stages of internalization of external costs. The results for the three power plants are shown below.

Table 30. Results of the Brazil Hydro Cycle Case Study

<table>
<tr><th colspan="2">Hydro-Electric Plants</th><th>Madeira</th><th colspan="2">Tucuruí</th><th>Serra da Mesa</th></tr>
<tr><td colspan="2">Installed Capacity</td><td>6450 MW</td><td>4000 MW</td><td>4375 MW</td><td>1275 MW</td></tr>
<tr><td rowspan="2">Externality (US $)</td><td>Increase on local health system</td><td>US $31,902,944.00 per year US $1.03 /MWh</td><td colspan="2">-</td><td>-</td></tr>
<tr><td>Increase in vector-borne diseases</td><td></td><td colspan="2">US $12,420,388.00 per year US $0,64/MWh</td><td></td></tr>
<tr><td>Externality Avoided (US $)</td><td>Increase in vector-borne diseases</td><td>US $26,929,031.00 per year US $0.87/MWh</td><td colspan="2"></td><td></td></tr>
</table>

Source: The Brazil Case Study Report under WP7, CASES

For the Rio Madeira Complex was calculated an additional cost of US$ 1.03/MWh for the increase in costs for the local health system. On the other hand, the programs put in place by the entrepreneurs to control endemic diseases have prevented externalities related to the endemic diseases. For this complex, the estimated control costs are about US$ 0.87/MWh, which have already been incorporated in the private cost. For the Tucurui plant, the endemic diseases not considered in the private costs have been calculated in an additional cost of US$ 0.64/MWh.

6.1.2 Adjusted results for higher consistency and comparability

Assuming an exchange rate of 1 € = 1.47 US$, the results of the Brazilian hydro fuel cycle are converted into Euro cents per kWh. The adjusted external costs of the three dams analyzed are shown in Table 31 below.

Table 31. Brazilian hydro fuel cycle.

Construction & power generation	Unit	Local health system	Vector born diseases	Total cost
Rio Madeira	€ cent/kWh	0.070	0.059	0.129
Tucurui	€ cent/kWh	-	0.043	0.043
Serra da Mesa	€ cent/kWh	0	0	0

6. 2 The Bulgarian Hydropower Power Fuel Cycle Case Study

6.2.1 Major assumptions and Calculation Results of the Study

The Bulgarian report covers three kinds of hydropower fuel cycles: small and medium sized run-of-river hydropower, dam-based hydropower, and pump-based storage hydropower. In Bulgaria, the definition of small and medium sized hydro is installed capacity up till 10 MW.

The Bulgarian government fixes a preferential grid-upload tariff of €40.00/MWh for electricity from small and medium sized hydropower generators. The tariff does not include VAT. In the Bulgaria study, this preferential tariff is taken as the private cost of small and medium sized run-of-river hydro projects.

The Bulgarian report does not elaborate on the methodology, assumptions and process for the calculation of external costs of hydropower. Instead, it simply gives the calculation results. Therefore the methodology has not been discussed further here. The results are shown in Table 32 below.

Table 32. Private, External (total health) and Social Costs of the Hydro Fuel Cycle in Bulgaria from 2007 to 2030

Year	Hydropower Type	Installed Capacity	Generation	Total Private Cost	External cost	Social Cost
		MW €/Mwhel	GWh/y	€/MWh$_{el}$	€/MWh$_{el}$	€/MWh$_{el}$
2007	HRR small & medium	106	250	40.00	2.00	42.00
	Hydro dam	1809	2700	55.00	5.00	60.00
	Hydro pump storage	1012	250	76.39	7.00	83.39
2010	HRR small & medium	106	265	41.21	2.00	43.21
	Hydro dam	1809	2 605	56.67	5.00	61.67
	Hydro pump storage	1012	175	78.70	7.00	85.70
2015	HRR small & medium	126	315	43.31	2.10	45.41
	Hydro dam	1894	2727	59.56	5.20	64.76
	Hydro pump storage	1012	280	82.72	7.30	90.02
2020	HRR small & medium	176	440	45.52	2.20	47.72
	Hydro dam	1984	2857	62.60	5.50	68.10
	Hydro pump storage	1012	315	86.94	7.80	94.74
2030	HRR small & medium	226	565	50.29	2.50	52.79
	Hydro dam	2104	3030	69.14	6.00	75.14
	Hydro pump storage	1012	280	96.03	8.00	104.03

6.2.2 Adjusted results for higher consistency and Comparability

The externalities of the Bulgarian hydro fuel cycle have been calculated for three different types of hydropower plants namely run-of-river hydro, dam hydro and pumped storage hydro. The Bulgarian team has not broken the external cost up into different steps and therefore only the total costs for the different plant types are given. Since the external costs are given in Euros in the country report, no currency conversions have been made. The numbers for the three plant types are shown in Table 33.

Table 33. The Bulgaria hydro fuel cycle

Construction & power generation	Unit	Total cost
Hydro Run of River	€ cent/kWh	0.2
Hydro Dam	€ cent/kWh	0.5
Hydro Pump Storage	€ cent/kWh	0.7

It can be seen from Table 33, that the external costs from Bulgarian hydro are generally low but higher for pumped storage and dam hydro than run-of-river. In the Bulgarian report it is mentioned that during the last ten years all the hydro dams in have been reconstructed and modernized. This has lead to restoration and improvement of their technical characteristics, but simultaneously restored their capital cost (component) in private costs.

6.3 Comparison and Analysis

The comparability of the results of the Brazilian and Bulgarian country studies is generally low. This is mainly because the Brazilian study only covers part of the health impacts during the construction and operation of hydropower projects, while the Bulgarian study just gives the total costs for the three types of hydropower fuel cycles. Some significant externalities have also not been considered in the studies. The emission of CH_4 from especially tropical hydro power reservoirs can be quite substantial and this burden has not been considered for the Brazilian case and it is unclear whether is has been included in the Bulgarian case study.

7. Comparative Assessment of the Wind, Solar PV and Biomass Fuel Cycles in Bulgaria and the Bio-diesel Fuel Cycle in Turkey.

This section covers all the non-hydro renewable energy fuel cycles included in the country case studies under WP7. The Turkish country report includes a case study on the bio-diesel fuel cycle, while the Bulgarian report covers 4 types of wind power fuel cycles, 2 solar PV fuel cycles, 1 solar thermal, 1 fuel cell and 3 biomass-for-electricity fuel cycles. As the Bulgarian fuel cycles do not include details about their assumptions and components of the external costs, all adjusted results for the Bulgarian non-hydro renewable fuel cycles are given in sub-section 7.5, instead of in a separate section in each of sub-sections 7.1, 7.2, and 7.3.

7.1 The Bulgarian Wind Power Fuel Cycle Case Study

According to the methodology in CASES DELIVERABLE NO. D.4.1, the total private costs should consist of ALLGC (Average Lifetime Levelised Generating Costs) plus back-up costs, especially for wind power. But the Bulgaria case study does not include the back-up costs. The Bulgaria report also emphasizes that the wind generators private costs in Bulgaria are higher than in the existing EU countries. This has to be explained with the lower hourly usage of the installed capacities.

The Bulgarian government has set the following preferential prices for wind power in the country:

- For wind generators with full effective annual period of exploitation up to 2250hours– €89.5/MWh;
- For wind generators with full effective annual period of exploitation over 2250 hours – €79.8/MWh

In the study, these preferential prices are used as the private costs of wind power fuel cycles (see Table 34).

Table 34. Private, external and social costs for Wind Power Fuel Cycles in Bulgaria, 2007-2030

Year	Wind power Type	Installed Capacity	Generation	Total Private Cost	External cost	Social Cost
		MW €/Mwhel	GWh/y	€/MWhel	€/MWhel	€/MWhel
2007	Wind second hand on-shore	2	2	60.00	2.00	62.00
	Wind new on-shore<2250 h	0		89.30	2.00	91.30
	Wind new on-shore>2250 h	0		79.59	2.00	81.59
	Wind off-shore	0		79.59	1.00	80.59
2010	Wind second hand on-shore	75	4 1	61.82	2.00	63.82
	Wind new on-shore<2250 h	0		92.01	2.00	94.01
	Wind new on-shore>2250 h	0		82.00	2.00	84.00
	Wind off-shore	0		82.00	1.00	83.00
2015	Wind second hand on-shore			64.97	2.10	67.07
	Wind new on-shore<2250 h	217	504	96.70	2.10	98.80
	Wind new on-shore>2250 h	0		86.18	2.10	88.28
	Wind off-shore	0		86.18	1.05	87.23
2020	Wind second hand on-shore	1000		68.29	2.20	70.49
	Wind new on-shore<2250 h	523	3 504	101.63	2.20	103.83
	Wind new on-shore>2250 h	0		90.58	2.20	92.78
	Wind off-shore	0		90.58	2.20	92.78
2030	Wind second hand on-shore	2000		75.43	2.50	77.93
	Wind new on-shore<2250 h	752	7 504	112.26	2.50	114.76
	Wind new on-shore>2250 h	0		100.06	2.50	102.56
	Wind off-shore	200	500	100.06	1.20	101.26

In the estimation of the external costs of the wind fuel cycle, the stages related to wind turbine production have not been included since the wind turbines used in Bulgaria are imported. Instead, the external cost mainly includes the noise and other negative effects, which are the same as in the rest of world. It can be seen from the Table 34 above, that the external costs of all on-shore wind is the same, 0.2 Euro cent per kWh, while the external cost of off-shore wind is half that of on-shore, namely 0.1 Euro cent per kWh. This can be explained by the fact, that the Bulgarian study only includes externalities from the operation stage where noise is a significant factor.

7.2 The Bulgarian solar PV, solar thermal, and fuel cell cycle case study

The Bulgarian team also includes solar PV, solar thermal and fuel cells in their fuel cycle external cost assessment.. Fuel cells, although also an electricity generating cycle, can not be considered as a real renewable fuel cycle since they can use a wide variety of fuels, including hydrogen and methane.

Like for the other renewable fuel cycles, the preferential prices set by the Bulgarian government are used as private costs in the Bulgaria case study. Most of the solar PVs used in Bulgaria are imported and hence the production of solar PV is not included in the external cost assessment. The Bulgarian study does not give any details about the methodology used for the external cost calculations and therefore it has not been elaborated further here. The results of the Bulgarian case study on solar PV, solar thermal and fuel cells are shown in Table 35. No estimates of the external costs of fuel cells and solar thermal are given.

Table 35. Private, external and social costs for Solar PV, Solar Thermal, and Fuel Cell Fuel Cycles in Bulgaria, 2007-2030

Year	Fuel cycle	Installed Capacity	Generation	Total Private Cost	External cost	Social Cost
		MW €/Mwhel	GWh/y	€/MWhel	€/MWhel	€/MWhel
2007	Photovoltaic PV more 5 kW	0		366.00	5.00	371.00
	Photovoltaic PV less 5 kW	0		399.00	5.00	404.00
	Solar thermal	0				0.00
	Fuel Cells	0				0.00
2010	Photovoltaic PV more 5 kW	0		366.00	5.00	371.00
	Photovoltaic PV less 5 kW	0		399.00	5.00	404.00
	Solar thermal	0				0.00
	Fuel Cells	0		110.00		110.00
2015	Photovoltaic PV more 5 kW	0		366.00	5.20	371.20
	Photovoltaic PV less 5 kW	0		399.00	5.20	404.20
	Solar thermal	0				0.00
	Fuel Cells	1	2	115.61		115.61
2020	Photovoltaic PV more 5 kW	0		366.00	5.50	371.50
	Photovoltaic PV less 5 kW	0		399.00	5.50	404.50
	Solar thermal	1	2	150.00		150.00
	Fuel Cells	2	4	121.51		121.51
2030	Photovoltaic PV more 5 kW	0		366.00	6.00	372.00
	Photovoltaic PV less 5 kW	0		399.00	6.00	405.00
	Solar thermal	2	4	155.00		155.00
	Fuel Cells	4	8	134.22		134.22

7.3 The Bulgarian Biomass Fuel Cycle Case Study

Like for the other renewable technologies, the private costs are based on the preferential prices set by the Bulgarian government:

- For Biomass wood chips - €109.70/MWh;
- For Biomass straw - €80.00/MWh;
- For Biomass power crops - €93.90/MWh;

As for wind turbines and solar PV, the biomass-fired power generators used in Bulgaria are imported from other countries. Therefore, the external cost assessment does not include the part related to the production of the generators. The results of the Bulgarian case study are given in Table 36.

Table 36. Private, External and Social costs for Biomass Fuel Cycles in Bulgaria, 2007-2030

Year	Biomass Fuel Cycle	Installed Capacity	Generation	Total Private Cost	External cost	Social Cost
		MW €/Mwhel	GWh/y	€/MWh$_{el}$	€/MWh$_{el}$	€/MWh$_{el}$
2007	Biomass wood chips	3	n.a.	109.70	10.00	119.70
	Biomass straw	0		80.00	8.00	88.00
	Biomass power crops	0		93.90	9.00	102.90
2010	Biomass wood chips	3	5	113.02	10.00	123.02
	Biomass straw	0		82.42	8.00	90.42
	Biomass power crops	1	1	96.75	9.00	105.75
2015	Biomass wood chips	5	9	118.79	10.40	129.19
	Biomass straw	2	3	86.63	8.40	95.03
	Biomass power crops	2	3	101.68	9.50	111.18
2020	Biomass wood chips	12	25	124.85	11.00	135.85
	Biomass straw	4	6	91.05	9.00	100.05
	Biomass power crops	3	5	106.87	10.00	116.87
2030	Biomass wood chips	15	30	137.91	12.00	149.91
	Biomass straw	8	10	100.57	10.00	110.57
	Biomass power crops	4	6	118.05	11.00	129.05

Adjusted results of the Bulgarian wind, solar, and biomass fuel cycles for higher consistency and comparability

To facilitate comparison, the Bulgarian case study results are converted into € cent/kWh (see Table 37). Since the Bulgarian cost results already are given in €/MWh, the cost numbers are only converted to the cost in cents per kWh. The external cost of wind power mainly depends on whether the wind farm is on-shore or off-shore. The solar PV external costs are the same for different installation types/sizes, while the external costs of biomass-fired based power fuel cycles are influenced by the type of biomass used.

Table 37. Adjusted Results of the Bulgarian Study on the External Costs of Wind, Solar PV and Biomass Fuel Cycles, 2007

Construction & power generation	Unit	External cost
Wind on-shore	€ cent/kWh	0.2
Wind off-shore	€ cent/kWh	0.1
Solar PV (>5kW)	€ cent/kWh	0.5
Solar PV (< 5kW)	€ cent/kWh	0.5
Biomass wood chips	€ cent/kWh	1.0
Biomass straw	€ cent/kWh	0.8
Biomass power crops	€ cent/kWh	0.9

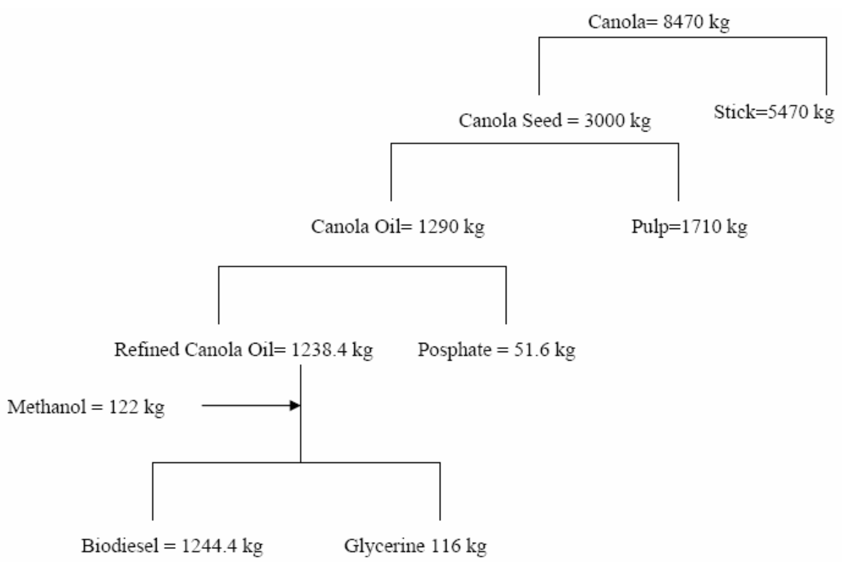
7.4 The Turkish Bio-diesel Fuel Cycle Case Study

7.4.1 Major assumptions and calculation results of the study

The bio-diesel life cycle assessment has the following stages: (1) Production of rapeseed; (2) Transport of rapeseed to a crushing facility; (3) Recovery of rapeseed oil at the crusher; (4) Transport of rapeseed oil to a bio-diesel manufacturing facility; (5) Conversion of rapeseed oil to bio-diesel; (6) Transport bio-diesel to the point of use; and (7) Use the fuel in a diesel engine.

The results of the Turkish case study of bio-diesel production from Canola Oil are given in the mass flow diagram shown in Figure 13. The study does not proceed to estimate the various emissions from the fuel cycle stages and it does not monetise any external costs. Since no complete burden data have been given in the study, it has not been possible to calculate any external costs.

Figure 13. Mass flow diagram of Biodiesel production from Canola oil



Source: The Turkey Report under WP7

7.5 Discussion and analysis

In this section, a variety of non-hydro renewable fuel cycles are covered, including bio-diesel, wind, solar PV, solar thermal, fuel cell, as well as biomass-based power generation. It has only been possible to show cost data from the Bulgarian case study, since the data available for the Turkish bio-diesel fuel cycle were too insufficient to be used for cost calculations. Since very little information has been given on the assumptions and methodologies used for estimating the costs in the Bulgarian case study it is not possible to discuss the choice of stages and burdens included.

8. General conclusions

8.1 Similarities and differences

Under WP7, the five countries conducted an external cost assessment on a wide variety of fuel cycles. Among the five countries, the Bulgarian case study is the most comprehensive in terms of the number of fuel cycles covered. Table 38 offers a overview of the external cost results of all the case studies after exchange rate and GHG cost adjustments.

Table 38. Summary Table of the Adjusted Results of All Fuel Cycle Case Studies under WP7

Fuel cycle	**Brazil** € cent/kWh	**Bulgaria** € cent/kWh	**China** € cent/kWh	**India** € cent/kWh	**Turkey** € cent/kWh
Coal		4.99	2.54	5.98	
Coal CHP		9.90			
Lignite		14.70			3.35
Lignite CHP		14.80			
Natural gas	1.20	4.06	0.92		
Biomass wood chips		1.0			
Biomass straw		0.8			
Biomass power crop		0.9			
Hydro run of river		0.2			
Hydro dam	0 / 0.043 / 0.129	0.5			
Hydro pumped st.		0.7			
Wind on-shore		0.2			
Wind off-shore		0.1			
Solar PV (>5kW)		0.5			
Solar PV (< 5kW)		0.5			

From Table 38 it can be seen, that after the same GHG costs have been applied to the country cost numbers and the costs have been converted to € cent/kWh, the different results exhibit the same magnitude. The coal fuel cycle generally has the highest external costs, followed by natural gas and the renewable technologies.

Impacts covered in the fossil fuel cycle assessment

The Chinese coal fuel cycle external cost is lower than that in India and Bulgaria, but as shown in Table 38, this could be explained by the fact that the Chinese coal fuel cycle assessment only covers the emissions during the power generation stage, while the Indian coal fuel cycle also covers coal mining, transportation, beneficiation and waste disposal. Although the Bulgarian coal fuel cycle study mainly includes the emissions from the power generation stage, the number in Table 38 is the Bulgarian team's total cost estimate and it is not clear how impacts were monetised and whether the external cost estimates cover more than emissions during power generation.

The Brazilian case study results for the hydro and natural gas fuel cycles are lower than of the Bulgarian case studies, but this could also be explained by the fact that the Brazilian external cost assessment is limited to the health impacts, while the Bulgarian estimate the total external costs.

The similarities of the results can be partly explained by the fact that for the coal and natural gas fuel cycles, CO_2 emissions constitute a major component in the total external costs. As the same cost of CO_2 has been applied to all studies except for Bulgaria a large fraction of the external costs becomes directly comparable. Table 39 shows the cost of CO_2 emissions from the coal fuel cycles in China, India and Turkey and it can be seen that the CO_2 emissions tend to constitute half or more of the total external cost of the fuel cycles.

Table 39. CO_2 emissions, adjusted costs and the total adjusted external costs of coal fuel cycles

	CO_2 emissions (g/kWh)	Adjusted CO_2 emission costs (€ cent/kWh)	Total Adjusted external cost (€ cent/kWh)	Source
China	816.64	1.69	2.54	Table 12
India	1368.66	2.826	5.976	Table 16
Turkey	1031.53	2.132	3.35	Table 20

8.2 Methodological challenges and data limitations

Table 40 gives an overview of the external costs given in physical units in the fossil fuel based fuel cycles covered in the case studies. It can be seen, that for all five countries, the external impacts quantified for coal and natural gas are often air pollution and GHG emissions, as well as solid waste (ash etc.) and liquid waste (mainly water). This shows that for external cost studies, these cost results are most readily available.

Table 40. Contents and Bases of Impact Valuation in the Case Studies

		Stage	Impacts quantified	Unit Price
China	Coal	Coal combustion at power plant	SO_2, NO_x, CO, CO_2, SP, Powdered Coal ash, Furnace Dust	China national standards on emission charges C and US Environmental Value Standard numbers
India	Coal	Mining:	CO_2 CH_4 RPM SPM SO_2 NO_x, Water*	SO2 and NOx: prices from the US market RPM and SPM: based on an Indian study of human health impacts GHG emissions: prices on the European carbon market Water: the water price for industrial consumers in India.
		Beneficiation:	CO_2, SO_2, NO_x, Water*	
		Transport:	CO_2, SO_2, NO_x	
		Power generation:	CO_2, SPM, SO_2, NO_x, Water*	
		Ash disposal:	CO_2, CH_4, SPM, SO_2, NO_x,	
Bulgaria	Hard coal CO	Power generation	CO2, SO2, NOx, PM2.5 and PM10	Not specified
	Hard coal CHP			
	Lignite CO			
	Lignite CHP			
Turkey	Lignite	Coal transportation and Power generation	CO2, SO2, SO2, TPS, liquid waste, solid waste	Results given in physical terms
China	Natural gas	Power generation	SO_2, CO_2, NOx, Suspended particles	China national standards on emission charges C and US Environmental Value Standard

				numbers
Brazil	Natural gas	Gas extraction and power generation	CO_2, CH_4 and N_2O	Increase in the incidence of respiratory diseases
Bulgaria	Natural gas CHP	Power generation	CO2, SO2, NOx, PM2.5 and PM10	Not specified

Except for Brazil, which focuses on a health impacts assessment, the other four countries do not follow the damage function approach of ExternE. This shows that the later steps of the ExternE damage function approach, namely: 1) Dispersion: to estimate scope and degree of impacts done, by taking into account the local climate and geographic situations and 2) define a dose-response functions, are more difficult to implement in the fuel life cycle case studies among the five countries. The last valuation step is mainly based on levels of emission charges set by the governments or the prices or charges used in the US. As a result, the study results do not consider the local population, climate, vegetation and geographic situation. When external costs are estimated on the basis of local government emission charges, the results are actually the shadow costs or opportunity costs taken into account by economic agents when deciding whether to take emission reduction measures or not.

The Brazilian case study was able to more strictly follow the ExternE damage function approach because the Brazilian research team has done two similar studies before and could base their research under WP7 on their previous work.

The results of the studies under WP7 reveals, that in order to expand the application of the ExternE approach and methodology in non-EU countries, a lot more needs to be done: the local research teams need to be trained and large research projects need to be implemented so that large quantities of data and on-site observations, interviews, questionnaires, expert estimates etc. can be carried out.

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